A GEOPHYSICAL STUDY OF MICROEARTHQUAKE ACTIVITY NEAR BOWMAN, SOUTH CAROLINA

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A GEOPHYSICAL STUDY OF MICROEARTHQUAKE ACTIVITY

NEAR BOWMAN, SOUTH CAROLINA

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SUMMARY

South Carolina earthquakes can be interpreted as forming a NW-SE trending zone of seismic activity that extends from Charleston to the Appalachians. Prior to the occurrence in 1971, and 1972, of a sequence of four intensity III or more earthquakes near Bowman, South Carolina, the area between Columbia and Charleston represented a significant apparent gap in this proposed zone.

From August, 1972, to March, 1973, microearthquake reconnaissance surveys near Bowman recorded six microearthquakes. Three were located to within ± 3 km. These microearthquake epicenters were insufficient to define a specific fault plane through the Bowman area. However, other recent microearthquakes near Lexington, South Carolina, and in the Charleston-Summerville area lend support to a hypothesized zone of seismic activity which passes through Bowman.

Three hundred and forty-four new points of gravity data in the vicinity of Bowman suggest that a nearly linear high density basement structure trending NE-SW underlies much of the Bowman microearthquake epicentral area. Magnetic data indicates that the structure also exhibits a higher magnetic susceptibility than the surrounding basement material. Using data from a geophone array which recorded

one of the Bowman microearthquakes, a basement velocity of 6.3 km/sec $\pm$ 0.7 km/sec was computed for the epicentral area. The high values for density, velocity and susceptibility of the basement structure imply that it is possibly diabase.

Irregularities in the gravity contour lines defining the linear anomaly appear to strike NW-SE. Analysis of a line of dense gravity data indicates that a steep 1.3 mgal gravity anomaly may be responsible for the NW-SE trending perturbations. Theoretical gravity profiles generated by two dimensional fault models closely approximate the steep anomaly observed in the profile of the detailed gravity line provided the modeled fault is placed at a depth of 0.32 km or less.

CHAPTER I

INTRODUCTION

The seismic history of South Carolina is dominated by the Charleston earthquake of August 31, 1886, its foreshocks and its aftershocks. The 1886 August 31, event initiated a period of increased seismic activity that lasted for approximately thirty years (Bollinger, 1972). This earthquake was felt over an area of approximately 2,000,000 square miles, including the undersea area, and it was felt with an intensity II (Rossi-Forel) as far away as New York and Bermuda. Savannah and Columbia, two cities approximately 90 miles from Charleston, experienced intensities of VIII and VIII to IX (Rossi-Forel), respectively (Dutton, 1889). In both cities, many chimneys were damaged, and some buildings suffered minor structural damage. In Charleston, the earthquake caused extensive damage and was rated as an intensity X on the Rossi-Forel scale.

Between 1754 and 1971, a total of 438 earthquakes have been reported as occurring in South Carolina (Bollinger, 1972). Of these, 402 have been located in the Charleston-Summerville area. Figure 1 shows the distribution of earthquakes in South Carolina through 1971. In the neighboring states of Alabama, North Carolina and Tennessee,

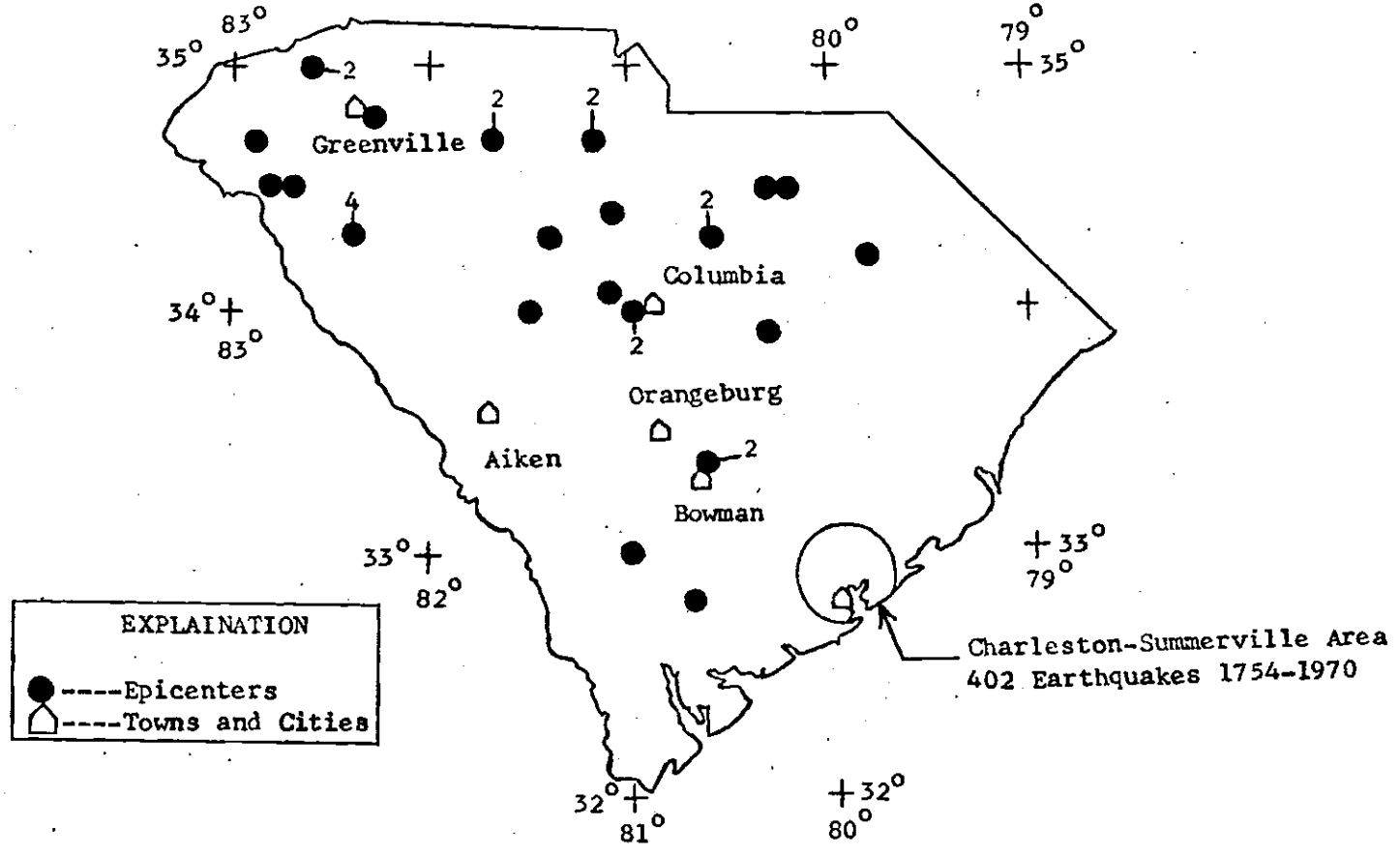


Figure 1. Seismicity Map for South Carolina (after Bollinger, 1972). Numbers Indicate Multiple Events.

epicenters generally trend NE-SW, paralleling the Appalachian structure. Multiple zones of seismic activity may parallel these zones in South Carolina. Many, for example Taber (1914), believe that the Charleston event of August, 1886, lies in a NE-SW trending zone near the coast.

Bollinger (1972) has interpreted the South Carolina events as forming a NW-SE trending zone of seismic activity that extends from Charleston to the Appalachians. This proposed belt of earthquake epicenters is perpendicular to the regional structure, but it parallels the numerous NW-SE oriented Mesozoic diabase dikes which are found in Alabama and South Carolina (Bollinger, 1972).

Prior to 1971, few earthquakes had been reported as occurring in central South Carolina. The region between Columbia and Charleston represented a significant apparent gap in the proposed NW-SE trending zone of seismic activity. Prior to May 19, 1971, Bowman, South Carolina, which is roughly midway between Columbia and Charleston, had no record of seismic activity within a radius of 50 km (Long, 1972). At 12:53 GMT on May 19, 1971, a maximum intensity IV (Modified Mercalli) earthquake occurred near Bowman. Within a period of eighteen months three additional events occurred. The largest and most recent event in the sequence was felt with an intensity V on February 3, 1972. Two aftershocks were felt with an intensity III on February 7, 1972. Several additional microearthquakes have subsequently been recorded

by portable smoked paper seismometers and interpreted as occurring within five kilometers of Bowman. These events are located approximately 60 kilometers northwest of the presumed epicenters of the August, 1886, Charleston earthquake.

The February 3, 1972, earthquake was the largest event which has been recorded in the Southeast since the installation of seismic station ATL in 1963. It was felt with an intensity of II to V (Modified Mercalli) over an area of 26,000 square miles, and Long (1972) computed its magnitude (M_L) to be 4.7. If it occurred along a previously active fault zone, the cumulative displacement could be large enough to be detected by geophysical survey methods. The continuing intermittent microearthquake activity also suggested that seismic data might provide enough epicenter locations to define the fault plane.

The purpose of this thesis study has been to investigate, using geophysical survey techniques, the nature and cause of the microearthquake activity near Bowman, South Carolina. Recently acquired microearthquake reconnaissance data and gravity data have been combined and correlated with existing geologic and seismic data. An attempt has been made to relate the Bowman microearthquake activity to the NW-SE trending zone of seismic activity hypothesized by Bollinger (1972) to extend across South Carolina from Charleston to the Appalachians.

CHAPTER II

GEOLOGIC SETTING AND VELOCITY MODEL

Bowman is located in Orangeburg County. Geologically, Orangeburg County is classed as the Lower Coastal Plain, and topographically it is essentially flat and featureless. Virtually all of the area's relief is due to sinkholes and the numerous NW-SE trending creeks and swamps. Elevations in the epicentral area vary from approximately 34 meters to almost 52 meters.

Figure 2 shows the distribution of major stratigraphic units present in the area of interest. According to Pooser (1965) the epicentral region is underlain by the Duplin Formation, the Santee Limestone and the Black Mingo Formation. The Black Mingo Formation underlies an extensive area, and it consists of quartzose sand, thin layers of silty clay and dark gray unctuous clay with small particles of Fuller's earth and pyrite. This layer ranges in thickness from 9 meters to as much as 38 meters. Much of the Black Mingo Formation was deposited in estuaries and littoral environments.

The Santee Limestone is a calcilutite to calcirudite that varies in color from creamy white to yellow. It is consolidated but not well indurated and is very fossiliferous.

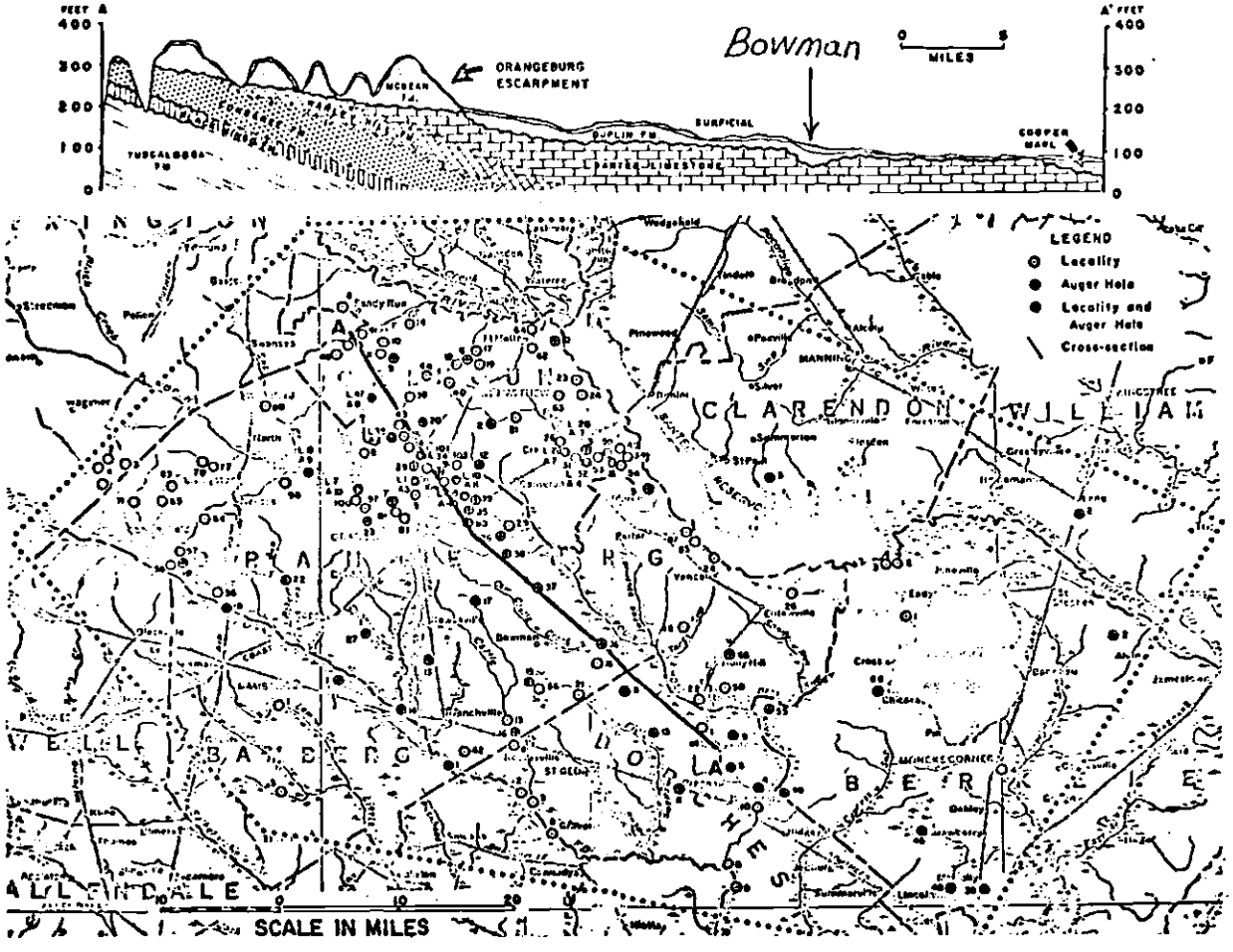


Figure 2. Geologic Cross Section A-A' Showing the Disposition of the Major Stratigraphic Units in the Bowman Area (after Pooser, 1965).

Near Bowman, it is overlain by a thin veneer of the Duplin Formation. The Duplin Formation is difficult to distinguish from the overlying surficial material. It is composed primarily of noncalcareous and calcareous quartzose sands with numerous shells (Pooser, 1965).

A refraction survey at Carn's Farm (see Figure 9) was conducted in an attempt to determine near surface velocities. The equipment used consisted of a portable tape recorder, amplifiers and 15 Hz exploration geophones. One geophone was used as a "shot break" and was moved progressively closer to the recording geophone beginning at a distance of 110 meters. A total of six "shots" were recorded. The energy source was a heavy object dropped from a height of nearly 2 meters. A first arrival corresponding to the direct P wave and a Rayleigh wave arrival were observed on each of the six records. Analysis of the data yielded apparent velocities of 0.81 km/sec $\pm$ 0.08 km/sec and 0.24 km/sec $\pm$ 0.02 km/sec for the P and Rayleigh waves respectively (Figure 3). Using the equations of White (1965, p 102), the velocity of the S wave was computed to be 0.25 km/sec $\pm$ 0.03 km/sec. The uncertainty in these numbers is due to uncertainty in interpreting the phase arrival times; however, these velocities are typical of sandy soils and unconsolidated formations such as the Duplin Formation. The velocities are representative of the surface layers (approximately 15 meters) only.

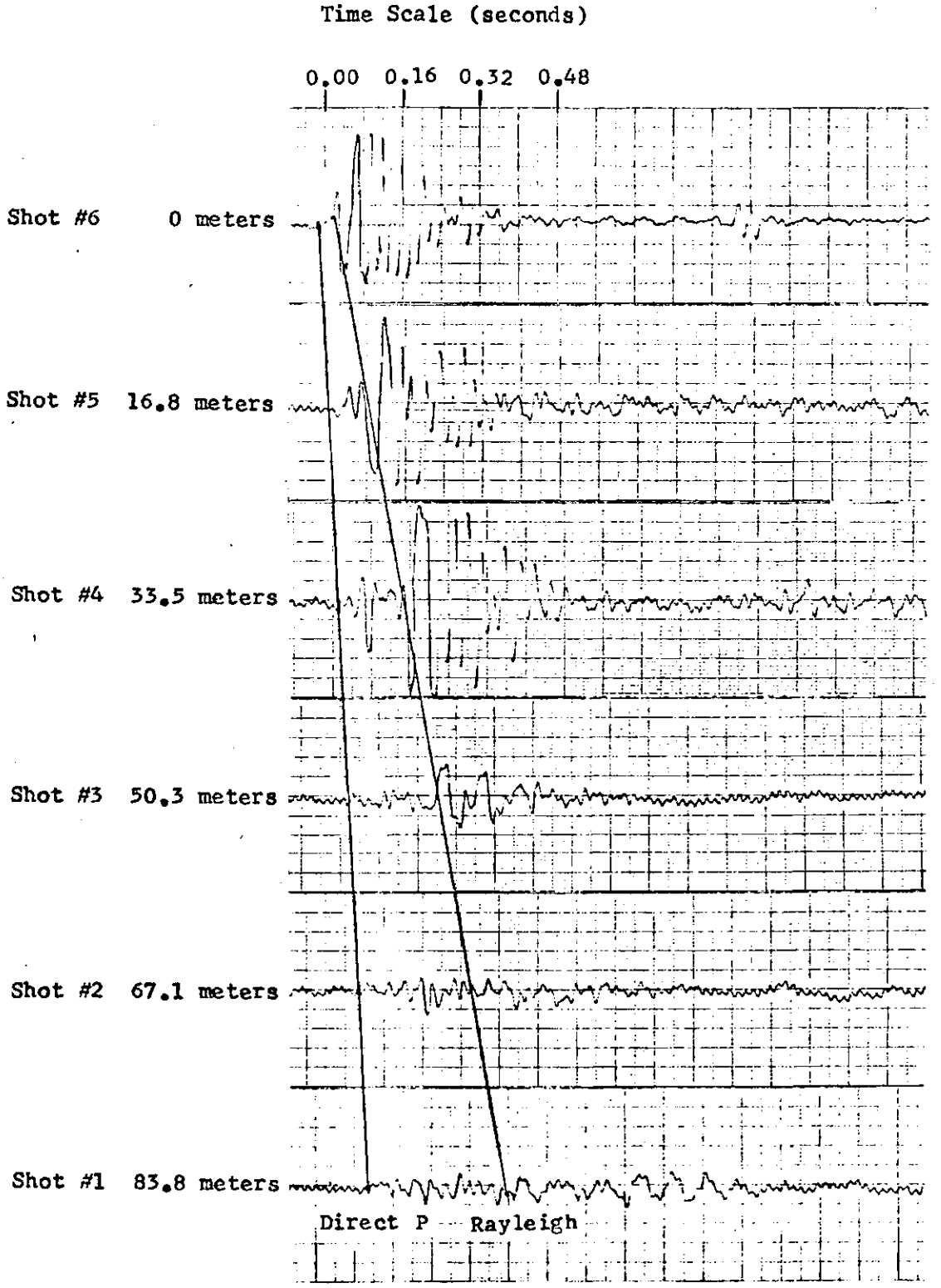


Figure 3. Carn Farm Refraction Survey Data.

Seismic refraction work by Woollard et al. (1957) was used to define the deeper velocity structure for the Bowman area. Data from refraction lines located north and west of Bowman in Orangeburg County and one southeast of Bowman in Dorchester County were used to interpolate the velocities and the depth to basement in the epicentral region. Both the depth to basement and the velocities of the surface layer appear to increase linearly to the southeast. The interpolated values for the depth to basement and the surface layer velocity are 460 meters and 2.4 km/sec respectively. The basement velocities show more variation and a linear interpolation is not justified. However, on the basis of the surrounding refraction data, 6.1 km/sec was considered for a first estimate for the basement velocity. Figure 4 shows the velocity structure and travel time curves computed for basement velocities of 6.9 km/sec. Standard time-distance relations for the two layer case were used in computing these curves (Dobrin, 1960).

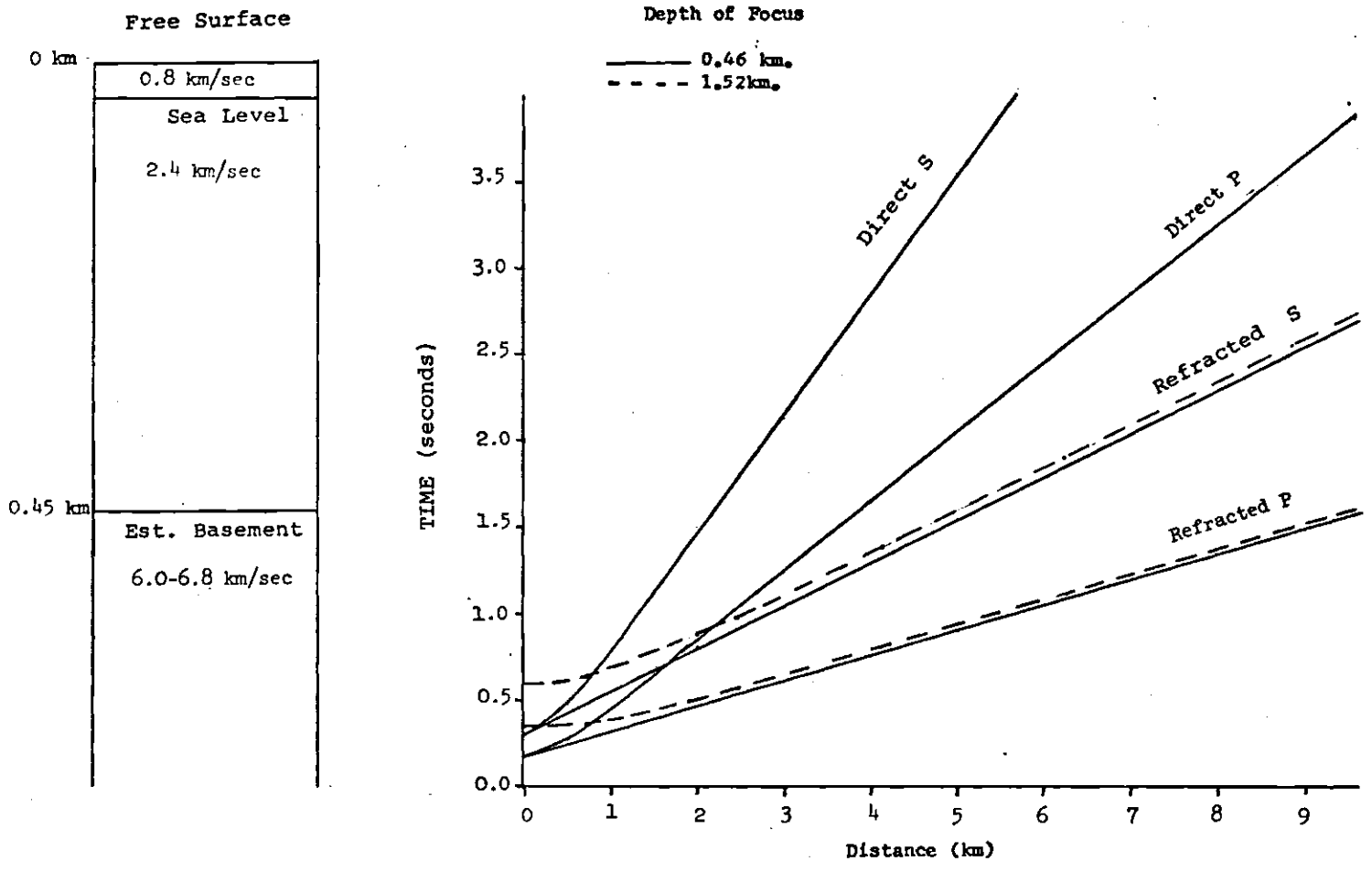


Figure 4. Velocity Structure and Travel Time Curves for a Basement Velocity of 6.9 km/sec. Travel Time Curves are Plotted for Focal Depths of 0.46 km and 1.52 km.

CHAPTER III

MICROEARTHQUAKE RECONNAISSANCE

Long (1972) computed the location of the epicenter of the 1972 February 3, event to be approximately 14 km northeast of Bowman. Subsequent to this, four microearthquake reconnaissance surveys were conducted in the vicinity of Bowman, resulting in approximately 20 days of noise-free recordings by three or more instruments. Additional data were obtained from a single smoked paper seismograph which recorded in Bowman for a ten week period from May through July, 1973.

Table 1 lists felt events which were recorded by station ATL and were located in the Bowman area. The times and locations of microearthquakes which were located in Bowman or immediately adjacent areas of the proposed NW-SE trending belt of seismic activity are given in Table 2. The list includes events from August 8, 1972, through July 1, 1973.

On August 8, 1972, a single portable seismograph located at Meyers Farm recorded a microearthquake (Figure 5). Analysis of the (S-P) time indicated the distance to the epicenter of the event to be 4.5 km $\pm$ 0.5 km. In December, 1972, a four station rectangular array was established with Meyers Farm as the southern corner of the rectangle (Figure 6).

Table 1. List of Felt Earthquakes Located near Bowman, South Carolina and Recorded by ATL and other Stations

Date - Time (GMT)	Maximum Intensity	M_L (from ATL records)	ATL Amplitude	Latitude	Longitude	Remarks
1971 May 19, 12h52m60s	IV	4.3	20.8	33.3°N	-80.6°W	NOAA
1971 July 31, 20h16m52s	III	4.3	20.	33.4°N	-80.7°W	NOAA
1971 August 11, 03h50m	I-II	3.9	9.26	--	--	ATL and BLA records indicate Orangeburg area
1972 February 3, 23h11m08s	V	4.7	69.3	33.46°N 33.476°N	-80.58°W -80.434°W	Long (1973) NOAA
1972 February 7, 02h46m	III	3.1	3.1	33°.46°N	-80.58°W	Long (1973)
1972 February 7, 02h53m	III	2.0	2.0	33°.46°N	-80.58°W	Long (1973)

Table 2. List of Events which Occurred Between August 8, 1972 and July 1, 1973 and were Located in Bowman or Adjacent Areas of the Proposed NW-SE Trending Zone of Seismic Activity

Date - Time (GMT)	Location	Remarks
1972 August 8, 08h00m	33°22.5'N-80°36.4'W±6km	recorded by one instrument near Bowman
1972 December 16, 06h52m	33°22.5'N-80°41.3'W±2km	recorded by three stations near Bowman
1973 March 22, 06h42m	33°28.5'N-80°43.0'W±3km	recorded by three stations near Bowman
1973 March 22, 14h42m	33°22.8'N-80°40.5'W±1km	recorded by four stations near Bowman
1973 March 25, 04h29m	33°04.2'N-80°06.9'N	NOAA--three detections
1973 March 27, 08h00m	Lexington, South Carolina	felt in Lexington
1973 March 27, 11h00m	Lexington, South Carolina	felt in Lexington
1973 April 1, 13h26m	33°02.4'N-80°08.9'W	NOAA--four detections
1973 April 1, 13h44m	33°02.2'N-80°07.0'W	NOAA--three detections
1973 April 1, 18h30m	33°00.7'N-80°09.0'W	NOAA--three detections
1973 April 18, 10h06m	33°02.4'N-80°16.7'W	NOAA--four detections
1973 May 4, 02h39m	33°02.0'N-80°10.2'W	NOAA--five detections
1973 May 27, 01h56m	33°20.8'N-80°40.6'W±5km	recorded by one instrument in Bowman
1973 June 9, 19h24m	32°55.7'N-80°09.8'W	NOAA--four detections also recorded in Bowman
1973 July 1, 08h20m	33°20.8'N-80°40.6'W	recorded in Bowman by one instrument, recorded at St. George, South Carolina (NOAA) by one station.

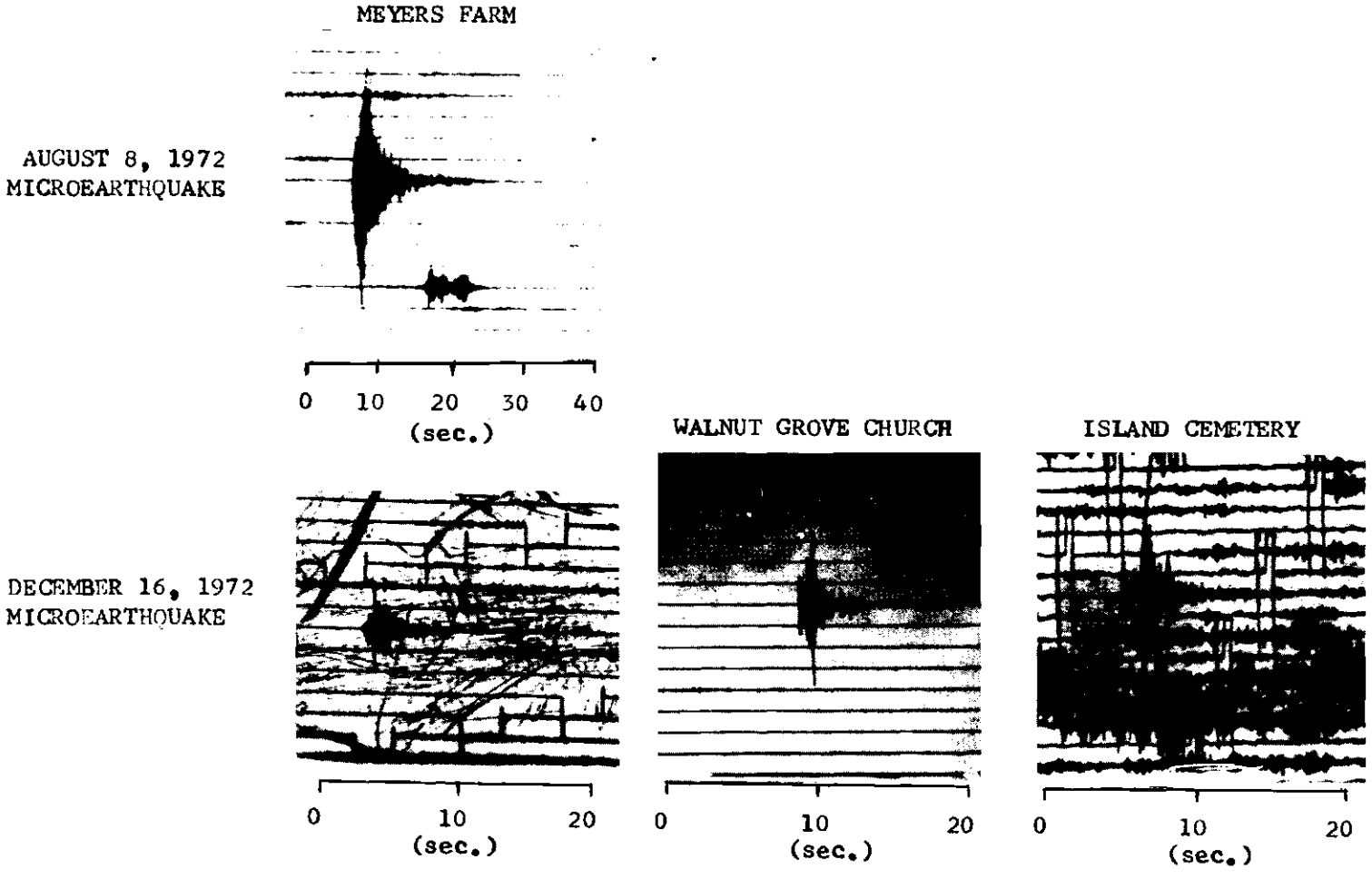


Figure 5. Photographs of the Smoked Paper Records of the 1972 August 8, and the 1972 December 16, Microearthquakes.

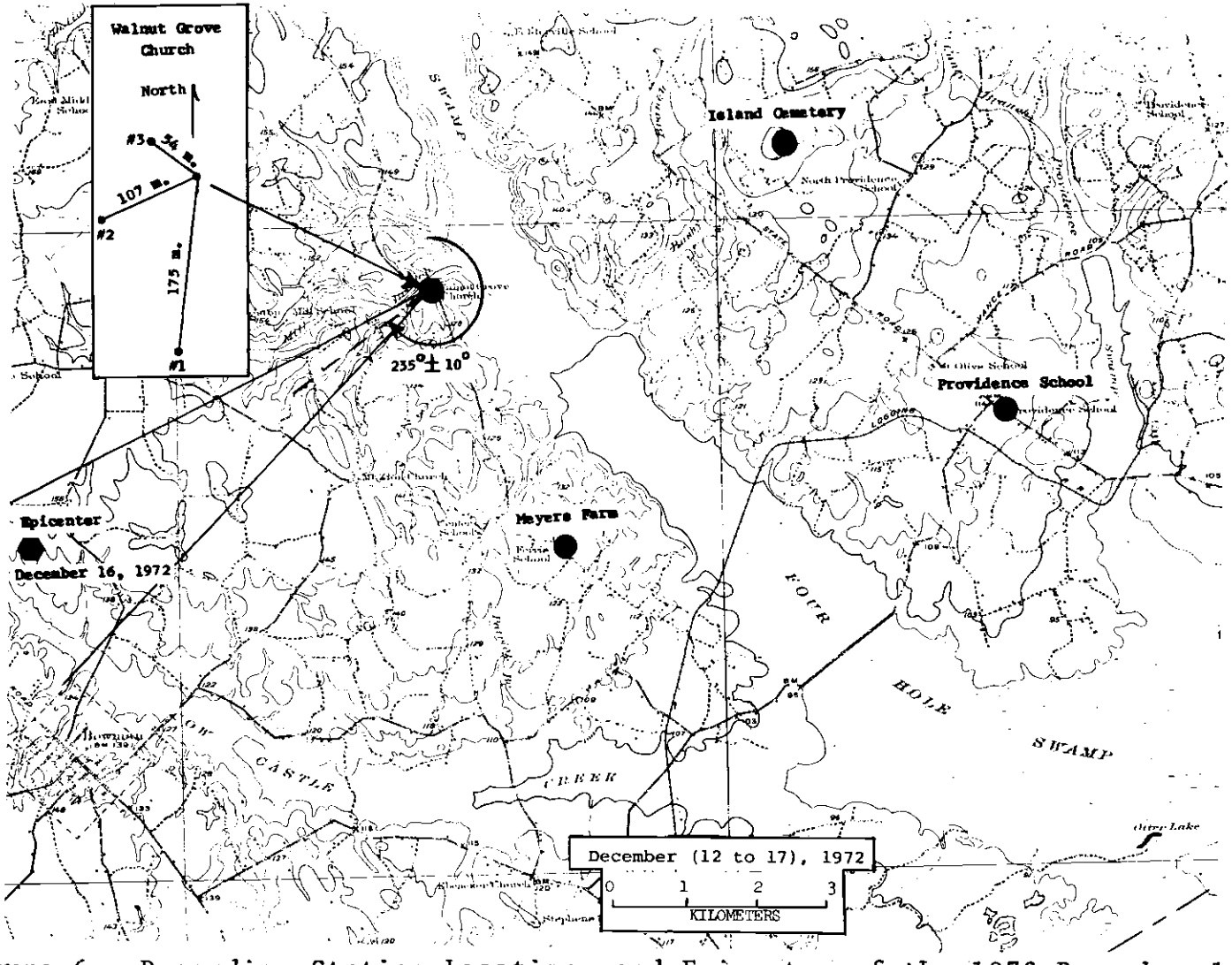


Figure 6. Recording Station Locations and Epicenter of the 1972 December 16, Microearthquake. The Array Insert is Centered at Walnut Grove Church. The Angle is the Azimuth from Walnut Grove Church to the Epicenter.

At Providence School the record of the event was hidden in background noise, but the smoked paper records of the other stations were sufficiently distinct for the identification of both P and S phases. A small geophone array at Walnut Grove Church recorded the event on magnetic tape and provided azimuthal control for the location of the epicenter. The azimuth from Walnut Grove Church to the epicenter of the event, measured clockwise from north, is 235° ± 10° (precision based on 95% certainty).

Using a basement velocity of 6.1 km/sec, efforts to locate the epicenter for this event failed to achieve convergence (see Appendix I for epicenter location techniques) suggesting that a higher basement velocity was required. With an assumed basement velocity of 6.9 km/sec, the epicenter was located west of the array at 33° 22.5'N-80° 41.3'W with a precision of ±2 km.

In March, 1973, two additional microearthquakes were recorded. The first event was recorded on 1973 March 22, 06h42m GMT by portable seismographs at Walnut Grove Church, Shiloh Church, Carn Farm and Bowman Cemetery (Figure 7). Three records were of good quality, but at Bowman Cemetery the event was barely recorded due to the low operating gain of the instrument. An interpretation of the (S-P) times of the event located the epicenter 18 km to the north of Bowman at 33°28.5'N-80°43.0'W with a precision of ±3 km (Figure 8). This location was based on an assumed focal depth of 0.46 km

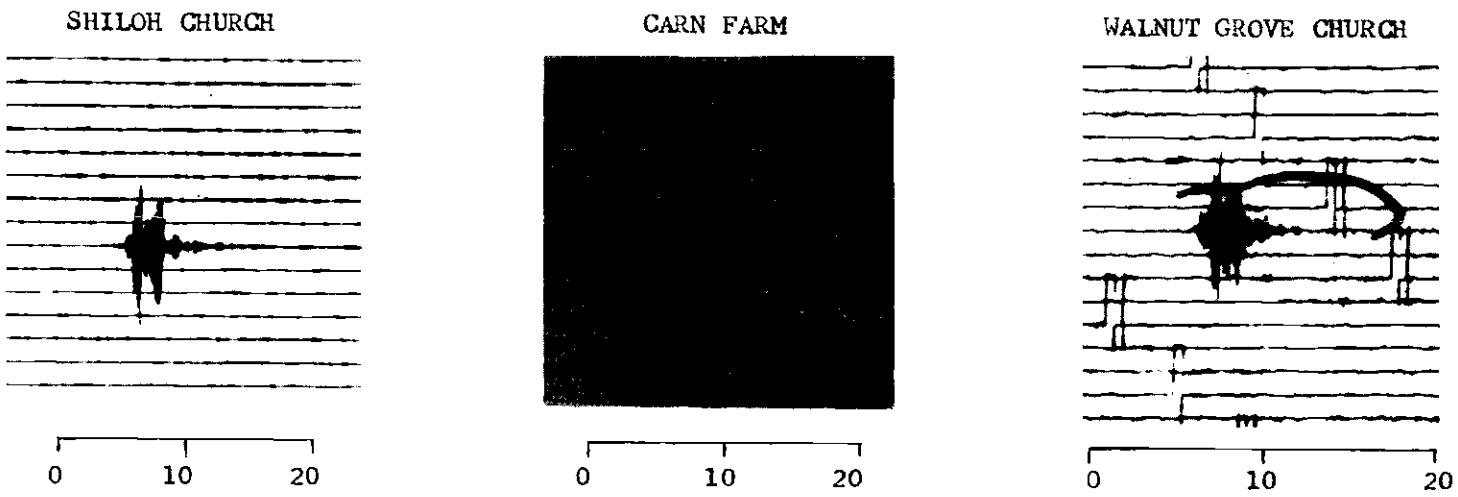


Figure 7. Photographs of the Smoked Paper Records of the 1973 March 22, 06h42m GMT Microearthquake.

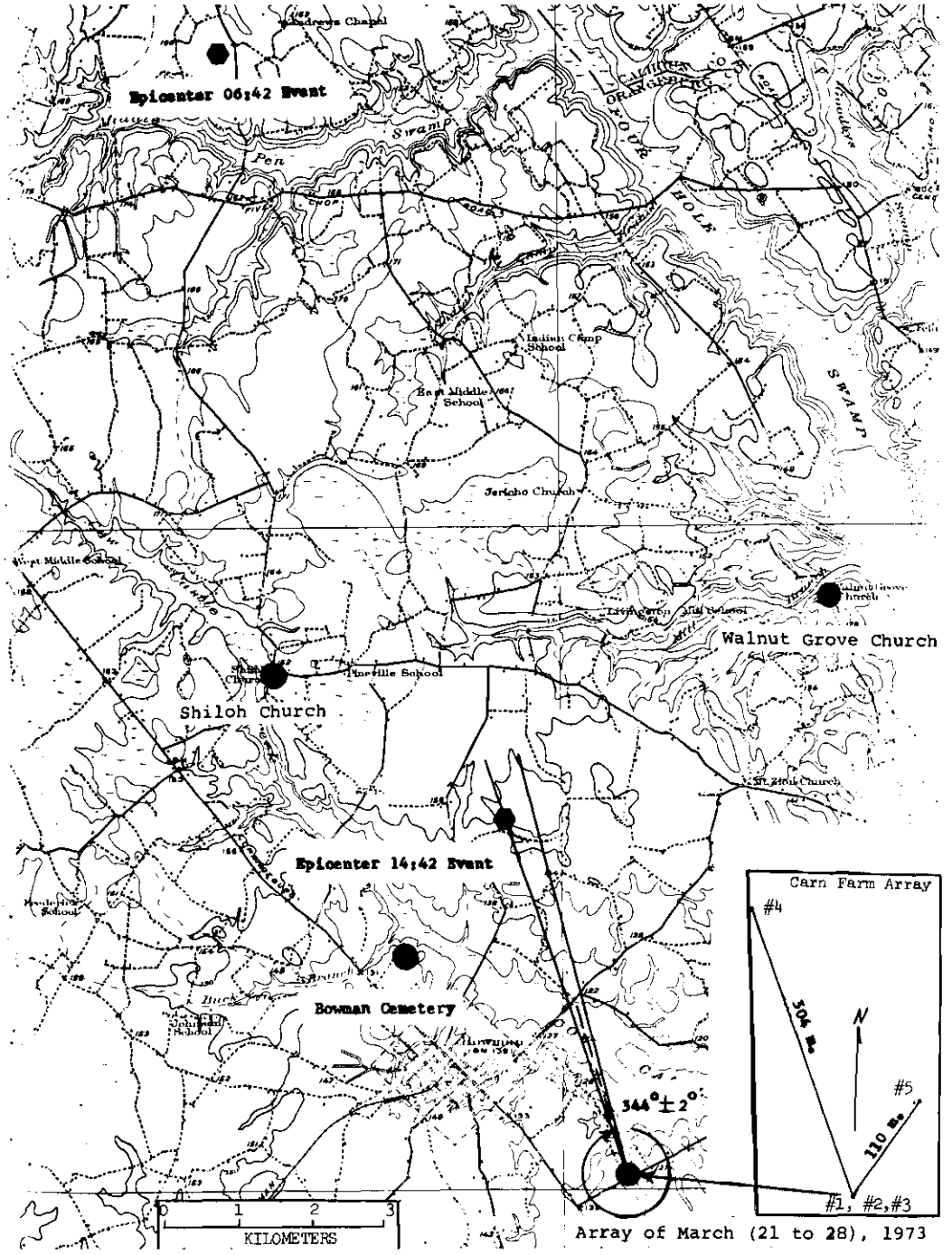


Figure 8. Recording Station Locations and Epicenters of the Two 1973 March 22, Microearthquakes. Array Insert is Centered at Carn Farm. The Angle is the Azimuth from Carn Farm to the Epicenter of the 14h42m GMT Event.

and a basement velocity of 6.9 km/sec.

The interpretation of the records of this event was made difficult by the low amplitude of the refracted P phase. The weak character of the refracted P phase could not be entirely attributable to recording distance. The 1972 December 16, event and the 1973 March 22, 06h42m GMT event were recorded at equivalent distances by seismographs at Island Cemetery and Walnut Grove Church respectively. The records of the events, however, showed refracted P phases of considerably different character. It is possible that differences in source mechanism, depth of focus or basement velocity structure could contribute to the variation. There were insufficient data to determine if there was any consistent azimuthal variation in the recorded character of the refracted P phase.

A second event was recorded at Walnut Grove Church, Shiloh Church and Bowman Cemetery by portable seismographs and at Carn Farm by both a portable seismograph and a small geophone array (Figure 9). The small array at Carn Farm recorded the microearthquake on magnetic tape. The event occurred on 1973 March 22, 14h42m GMT. Using a basement velocity of 6.9 km/sec and a focal depth of 0.6 km, the epicenter was located at 33° 22.8'N-80° 40.5'W with a precision of $\pm$1 km. Table 3 lists the origin times and epicenters of the three events recorded by arrays as well as the locations of the recording seismographs.

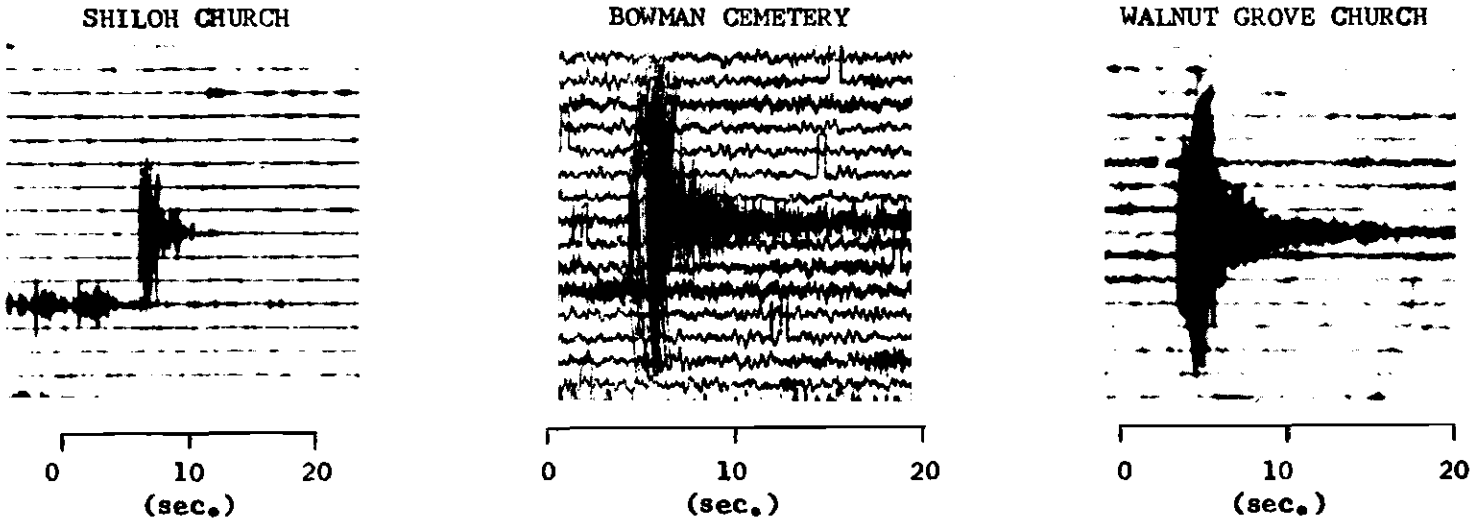


Figure 9. Photographs of the Smoked Paper Records of the 1973 March 22, 14h42m GMT Microearthquake.

Table 3. List of Microearthquakes Recorded by Arrays

Event: December 16, 1972 Time: 06h52m GMT
Location (Error-Grid): Lat. 33° 22.5' Long. 80° 41.3'
Location (Do-All): Lat. 33° 22.57' Long. 80° 41.26'
T_o = 0.02 (sec)

Recording Station	Latitude	Longitude	(S-P) (Seconds)
Island Cemetery	33.426	80.573	1.39
Meyers Farm	33.375	80.606	0.94
Walnut Grove Church	33.408	80.626	0.86
Providence School*	33.392	80.540	--

Event: March 22, 1973 Time: 09h42m GMT
Location (Error-Grid): Lat. 33° 28.5' Long. 80° 43.0'
Location (Do-All): Lat. 33° 28.44' Long. 80° 43.11'
T_o = 0.05 (sec)

Recording Station	Latitude	Longitude	(S-P) (Seconds)
Walnut Grove Church	33.408	80.626	1.33
Carn Farm	33.335	80.657	1.88
Shiloh Church	33.399	80.709	1.04
Bowman Cemetery*	33.363	80.689	--

Event: March 22, 1973 Time: 14h42m GMT
Location (Error-Grid): Lat. 33° 22.8' Long. 80° 40.5'

Recording Station	Latitude	Longitude	(S-P) (Seconds)
Walnut Grove Church	33.408	80.626	0.69
Carn Farm	33.335	80.657	0.61
Shiloh Church	33.399	80.709	0.45
Bowman Cemetery*	33.363	80.689	--

*Records from these stations were of poor quality and, therefore, were not used in locating the epicenters.

The array at Carn Farm was a tripartite array with a three component geophone cluster at one corner. Five channels of data and one of time were recorded on a seven channel Honeywell tape unit. The data from the analog tape was filtered with a 100 Hz low pass filter, digitized and plotted (Figure 10).

The array size was measured to a precision of ± 2 meters (Figure 11). Arrival times across the array relative to channel 4 were:

Ch 4	0.0 $\pm$ 0.005 sec	
Ch 5	0.037 $\pm$ 0.005 sec	= $t_1 \pm 0.005$ sec
Ch 1,2,3	0.048 $\pm$ 0.005 sec	= $t_2 \pm 0.005$ sec

In the computations of the velocity and azimuth, the seismic wavefront was assumed to be a straight line as it crossed the array. If the wavefront makes an angle B with the line from Ch 4 to Ch 2, an analytic expression for the apparent velocity across the array is:

$$Vap = \frac{D_1 \cos(B) - D_2 \cos(A-B)}{t_1} \qquad (1)$$

$$Vap = \frac{D_1 \cos(B)}{t_2} \qquad (2)$$

These equations are satisfied when B = 3.9° and Vap = 6.3 km/sec. Since the errors in D_1, D_2 and A are very small compared with the errors in t_1 and t_2, the errors for ΔV and B can be computed by applying standard error analysis

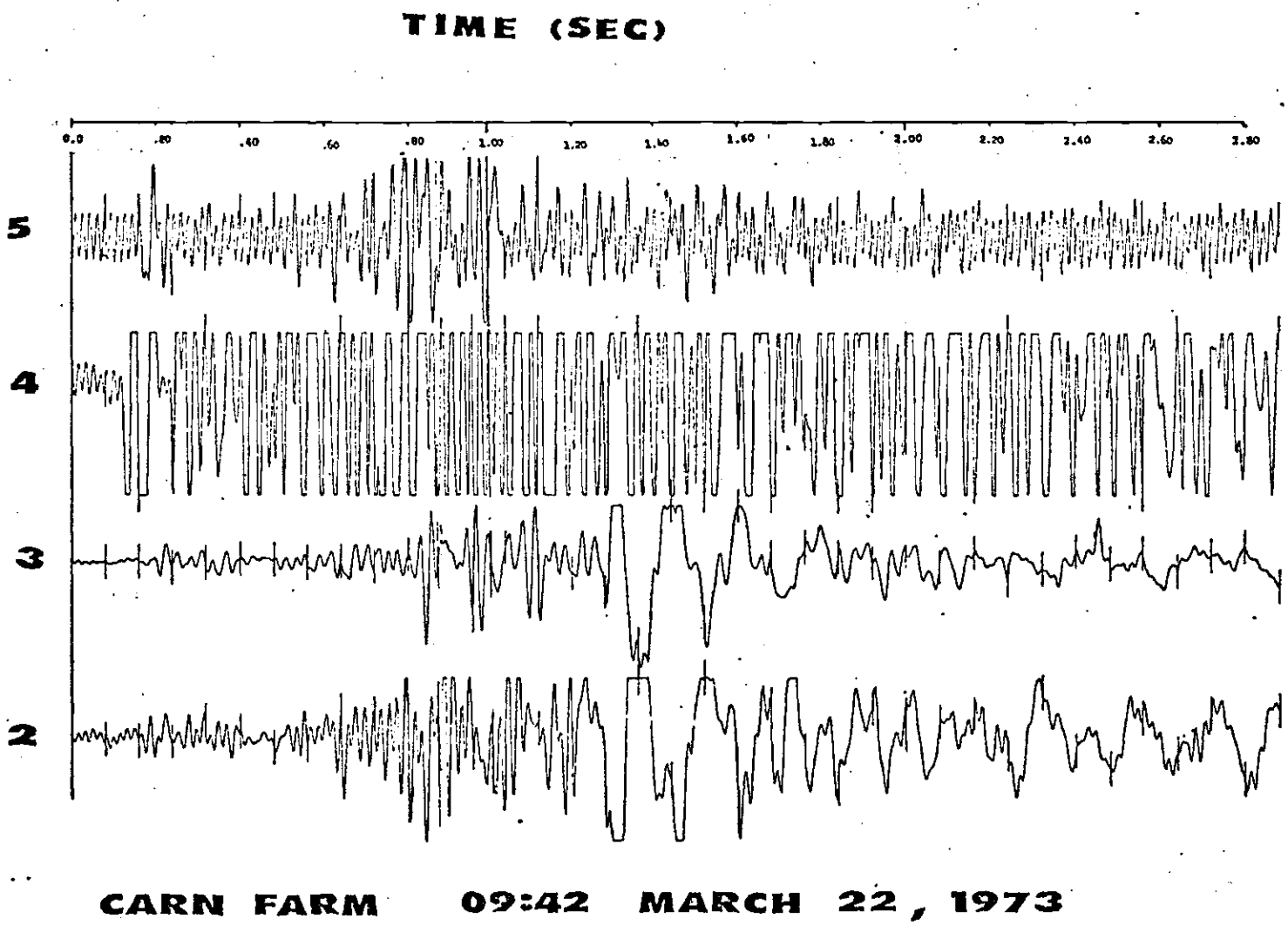


Figure 10. Digitized and Filtered Trace of the Carn Farm Array Recording of the 1973 March 22, 14h42m GMT Event.

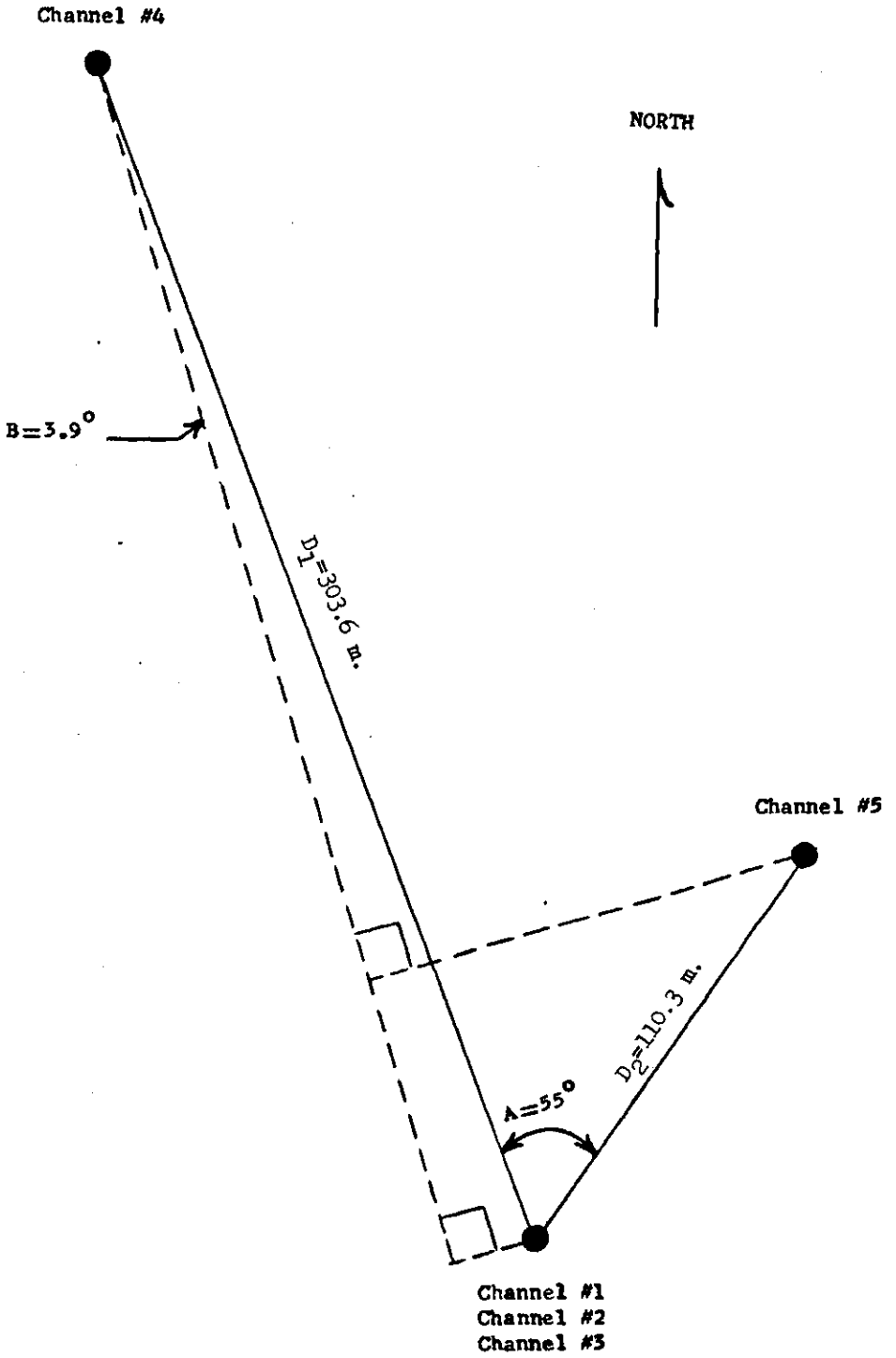


Figure 11. Angles and Dimensions of the Carn Farm Geophone Array.

techniques to equation (2). The errors for ΔV and B were computed as follows:

$$\Delta V = \sqrt{\left(\frac{\partial Vap}{\partial t_2}\right)^2 \Delta t^2} \qquad B = \arccos\left[\frac{(Vap)(t_2)}{D_1}\right]$$

$$\Delta V = 0.7 \text{ km/sec} \qquad \Delta AZ = \Delta B = \sqrt{\left(\frac{\partial B}{\partial Vap}\right)^2 (\Delta Vap)^2 + \left(\frac{\partial B}{\partial t_2}\right)^2 (\Delta t_2)^2}$$

$$\Delta AZ = 2.1^\circ$$

Therefore, the apparent velocity across the array at Carn Farm was 6.3 km/sec $\pm$ 0.7 km/sec. Using the refraction lines of Woollard *et al.* (1957) located nearest Bowman, an approximate value of 0.1° to the southeast was computed as the local dip of the basement. The maximum effect of this dip on the velocity across the array was computed to be $\pm$0.1 km/sec. Therefore, the apparent velocity may be taken as a valid basement velocity.

Measured clockwise from the north, the azimuth (AZ) from the south corner of the array to the seismic source of the 1973 March 22, 14h42m GMT event was 343.5° $\pm$ 2.1° (Figure 8).

CHAPTER IV

GRAVITY DATA

Excluding base stations, 344 new gravity readings have been obtained in the vicinity of Bowman, South Carolina. These have been combined with existing data (courtesy of Dr. G. P. Woollard) and contour plotted to produce a regional Bouguer anomaly map (Figure 12). The most distinctive feature of the regional map is a 20 mgal high northeast of the epicentral area which extends into a +12 mgal linear anomaly and runs through the epicentral region and to the southwest. The location of the epicenters of microearthquakes near the linear gravity high contradicts the proposal of Taber (1914) that South Carolina coastal plane earthquakes are the result of movement along existing faults in Trassic basins. In addition, the regional gradients are seen to be much too gentle to represent large faults in the basement. Since the observed gravity highs probably are not caused by variations in the depth to basement, they are most likely the expressions of density contrasts in the basement. The existence of a basement rock of high density which is responsible for the linear gravity anomaly is compatable with the apparent velocity observed at Carn Farm.

The epicentral region is mapped in greater detail in

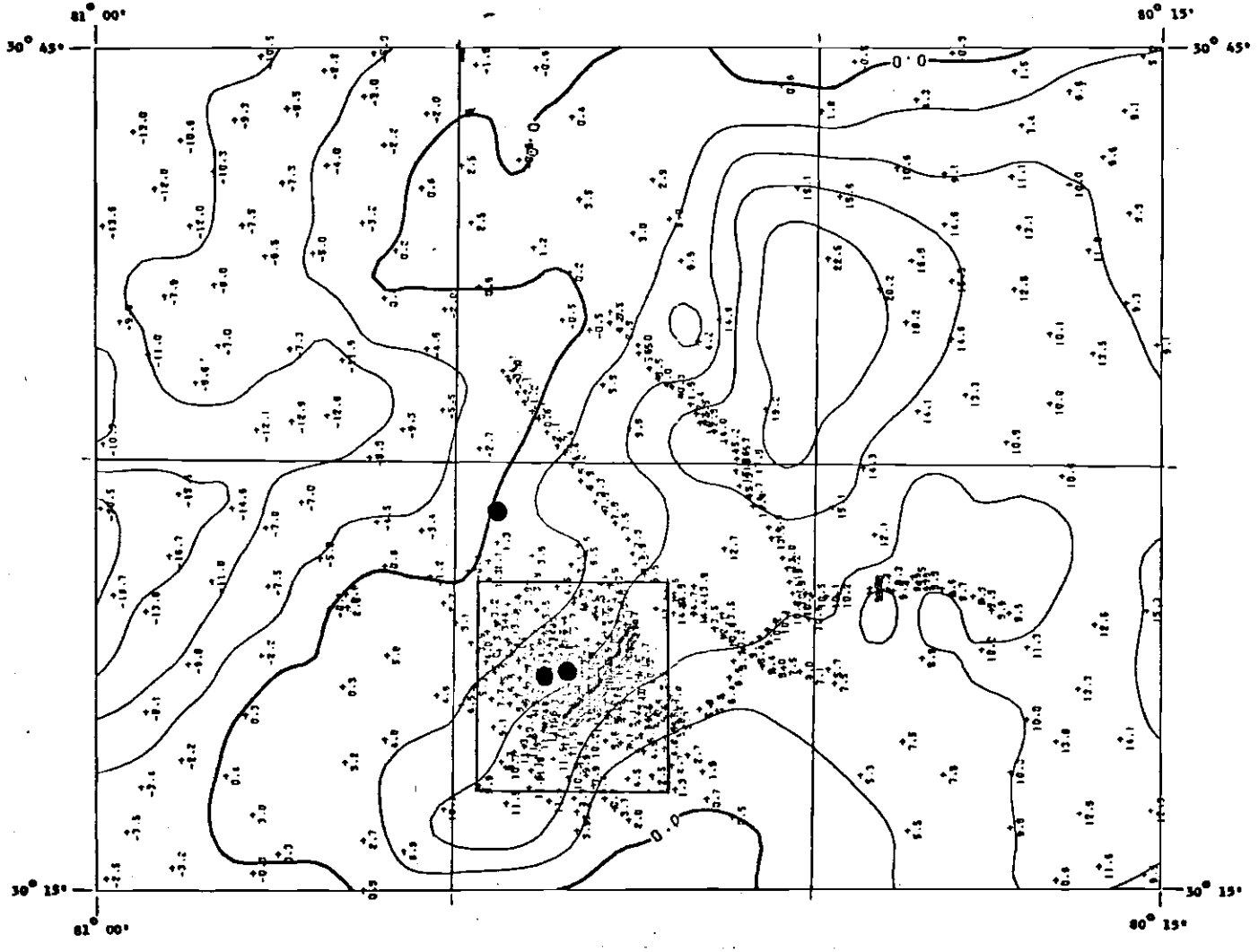


Figure 12. Regional Simple Bouguer Anomaly Map. Epicenters are Indicated and the Area of the Smaller Scale Bouguer Anomaly Map is Outlined.

Figure 13. There are irregularities in the NE-SW trending linear gravity anomaly. Near the epicentral region the width of the anomaly is constricted and its magnitude decreased. Two gravity profiles (Figure 13) perpendicular to the strike of the linear anomaly were used to develop models representative of basement density contrasts which could be responsible for the observed anomaly (Figure 14). A model varying in width from 6 km to 7 km and extending downward for 10 km to 12 km produces a gravity profile the shape of which agrees well with the shape of the profiles along lines 1 and 2. The gravity values of the theoretical profiles closely resemble the observed values along profiles 1 and 2, provided the models, which represent hypothesized structures, are assigned positive density contrasts with the surrounding basement material of 0.1 gm/cc to 0.09 gm/cc. With the exception of Shiloh Church, all of the smoked paper seismograph recording sites were over the modeled structure. This lends support to the 6.9 km/sec basement velocity required to achieve convergence for the epicenter location computed for the 1972 December 16, microearthquake.

The models discussed above can not explain the perturbations observed along the 0 mgal anomaly lines of Figure 12 nor the smaller perturbations observable in the 1 mgal contours of Figure 13. These irregularities (see Profile 2, Figure 13) in the contour lines defining the linear gravity anomaly appear to strike NW-SE, running essentially

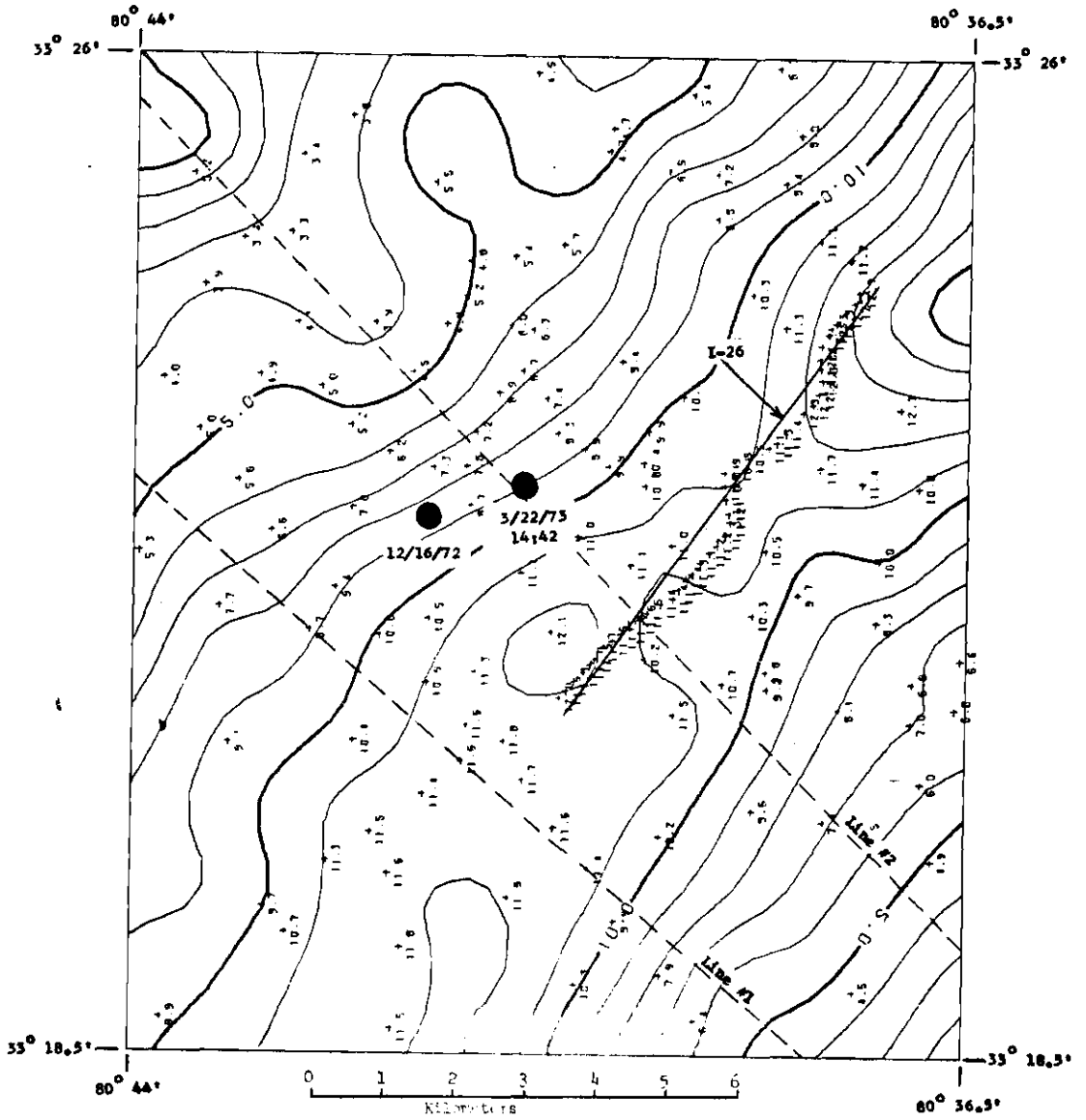


Figure 13. Simple Bouguer Anomaly Map of the Principal Epicentral Area. Epicenters are Located and the Gravity Profiles 1 and 2 are Indicated. Solid Line Along the Axis of the Linear Anomaly is the Line onto which the Detailed Gravity Line Data were Projected to Produce the Profile in Figure 15.

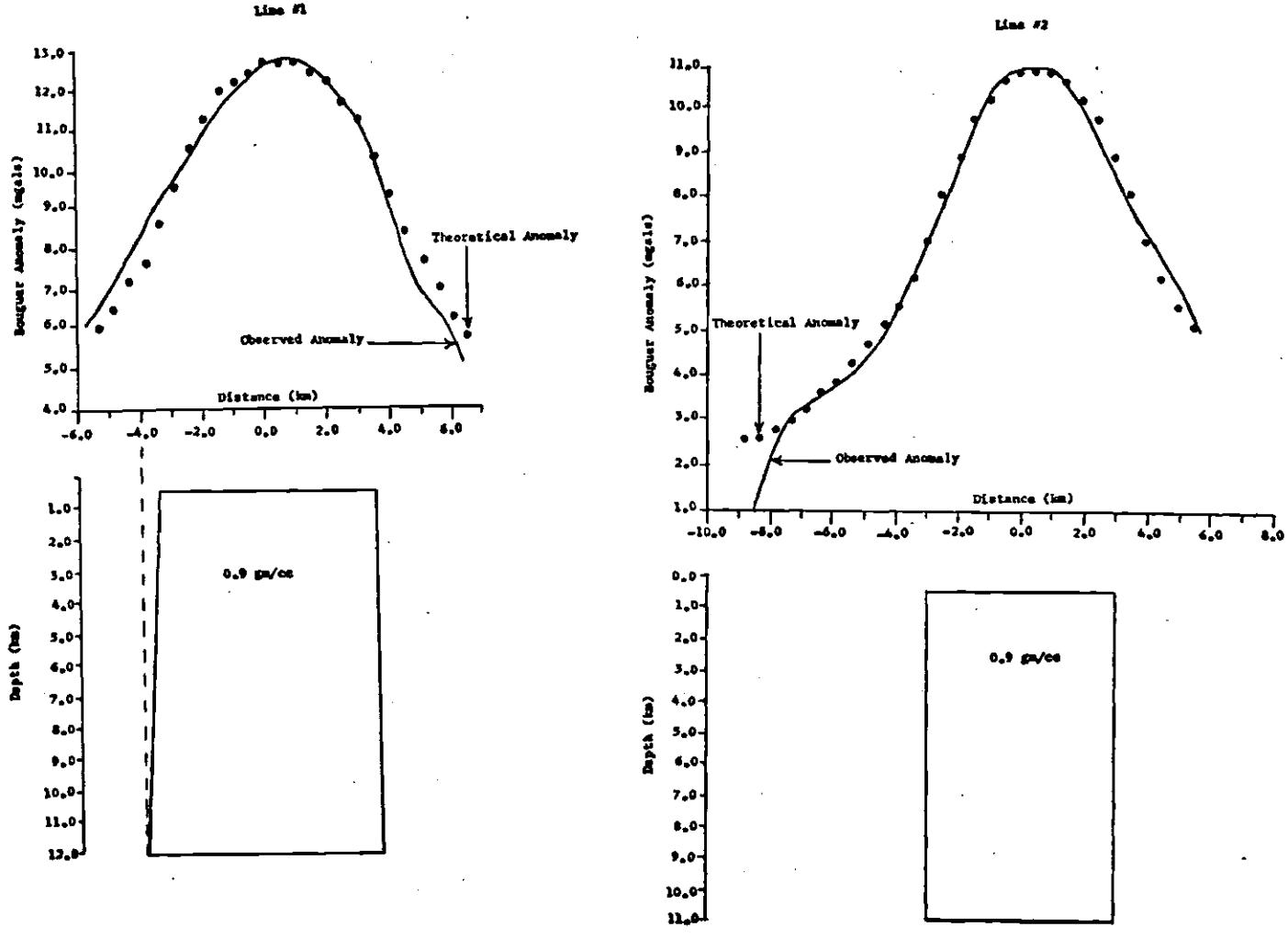


Figure 14. Comparison of the Theoretical Gravity Profiles of Two Basement Structure Models to the Profiles Along Gravity Lines 1 and 2.

perpendicular to the modeled structure and passing very near the epicentral region. The perturbations may reflect changes in thickness of the structure responsible for the linear gravity anomaly or may be the result of a basement feature unrelated to the source of the anomaly.

A line of closely spaced (on the order of 150 meters) gravity readings were made along a portion of the axis of the linear gravity anomaly in an attempt to specifically identify the nature of the NW-SE trending perturbations. The location of the gravity line is delineated by the closely spaced data points in Figure 13. A very sharp 1.3 mgal jump in gravity values occurs along the detailed line near its intersection with interstate 26 (Figure 15). The validity and effect of the Bouguer reduction density was tested by comparing a series of Bouguer gravity profiles of the detailed line with the elevation profile. Each profile in the series was calculated after assuming a different value for the Bouguer density within the range of 2.0 gm/cc to 3.0 gm/cc (Figure 16). The profile which has the least correlation with the sharp irregularities of the topography is preferable (Grant and West, 1965). Since all of the profiles in Figure 16 show equal correlation with the topography, the standard choice of 2.67 gm/cc for the Bouguer reduction density is as appropriate as any other.

If there was a density contrast between the faulted bed and the overlying material, a horizontal bed having a

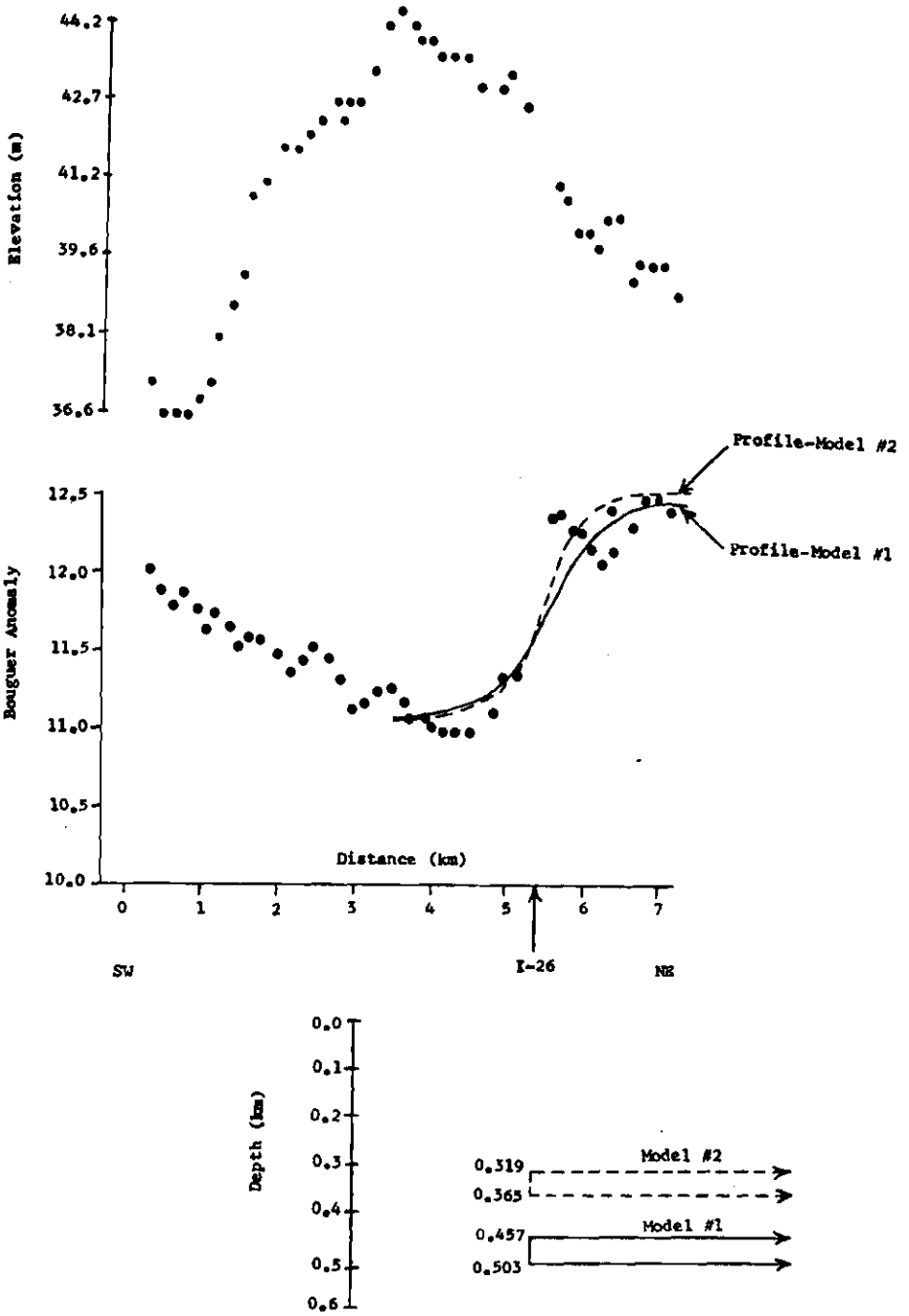


Figure 15. Comparison of the Theoretical Gravity Profile of Two Fault Models to the Steep Anomaly Observed along the Line of Dense Gravity Data.

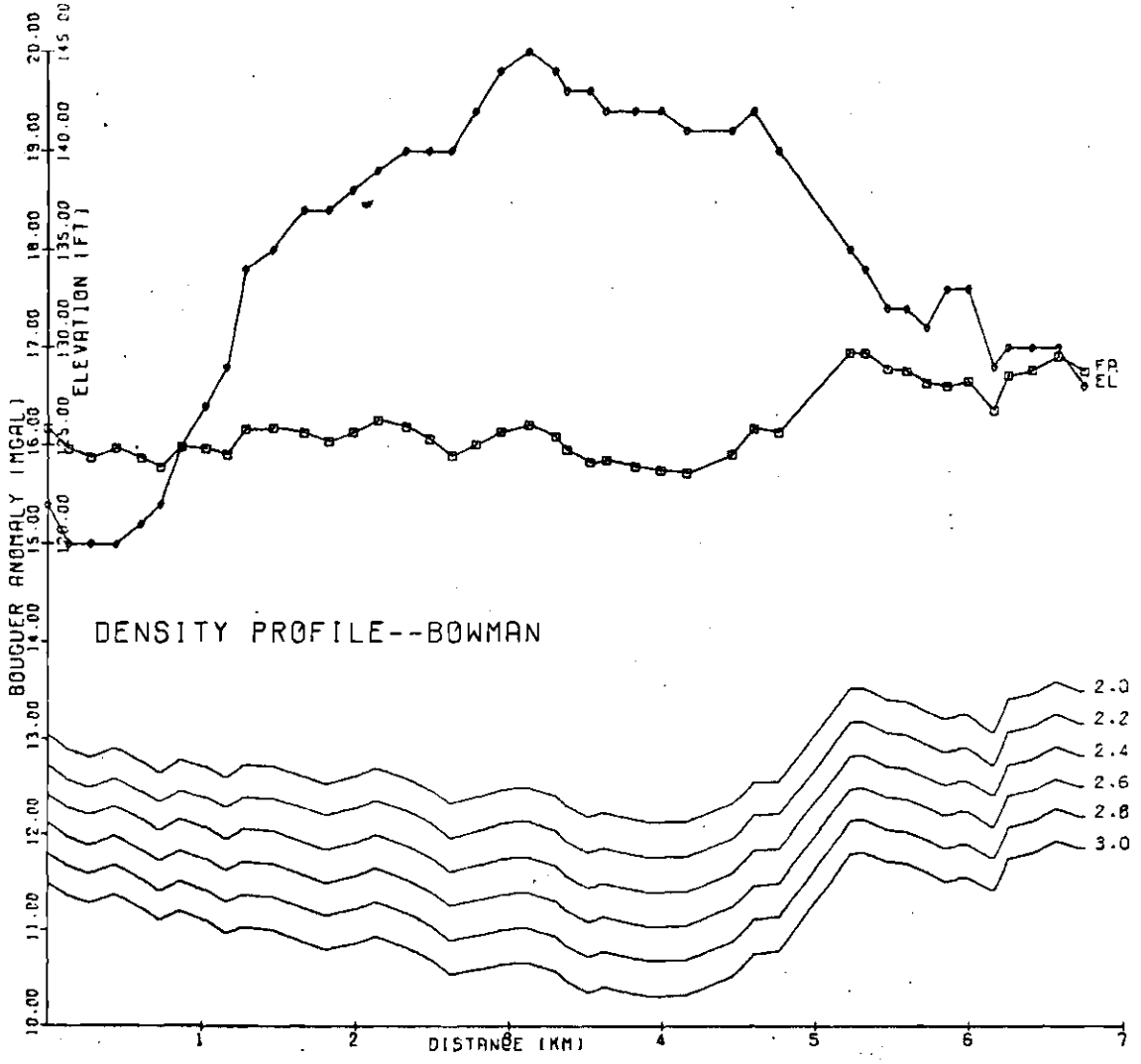


Figure 16. Elevation, Free Air Anomaly, and Plots of the Simple Bouguer Anomaly of the Detailed Line with Different Values for the Bouguer Reduction Density.

normal fault would produce a similar anomaly along a profile perpendicular to the vertical edge of the fault. This situation can be modeled using a semi-infinite horizontal slab of uniform thickness which ends with a vertical edge on one side. The depth to the top of the slab represents the depth to the fault and the density assigned the slab represents the density contrast between the faulted bed and the overlying material.

Using the density-velocity curves of Woollard (1959), a surface layer with a velocity of 2.4 km/sec would have a density of 2.1 gm/cc. Similarly, for a basement rock with a velocity of 6.9 km/sec the density would be 3.0 gm/cc.

The technique of Talwani, Worzel and Landisman (1959) was used to compute the gravity profile of a two dimensional model representing a fault. The density of the slab was taken to be 0.9 gm/cc and the top of the slab was placed at 0.46 km which is the assumed depth to basement in the Bowman area. When the two dimensional model was given a thickness of approximately 46 meters, the amplitude of the gravity profile of the model closely approximated the 1.3 mgal jump observed in the profile of the detailed line. The gravity profile of the model was much smoother than the observed jump. Since the shape of the theoretical profile was dependent only on the depth of the model, the top of the slab was raised above the basement so that the theoretical profile would more nearly match the observed profile. This strongly

suggests that the structure which is responsible for the sharp anomaly in the detailed line extends above the basement into the surface layer material.

A second derivative simple Bouguer anomaly map which includes the first detailed line data exhibits some evidence of a NW-SE trending feature. There is no topographic evidence of the high ridge or of the possible fault line in a second derivative elevation plot of the same area. This is not surprising since the surface geology of the area is such that any elevated features would be subject to rapid weathering and erosion.

If the sharp anomaly of the first detailed line is taken to be the expression of a fault, the continuity of the linear anomaly across the fault plane suggests that there has been less than 2.0 km cumulative horizontal movement along the fault.

CHAPTER V

MAGNETIC DATA

Magnetic data for Bowman and the surrounding area were taken from an aeromagnetic map of the Savannah River Plant area (Petty, et al., 1965). The data (Figure 17), contour plotted with an interval of 100 gammas, show a +2,500 gamma ridge which correlates with the positive ridge shown on the gravity plots and tends to support the possibility that a diabase structure in the basement is responsible for the anomalies. The magnetic data end a few kilometers east of Bowman. The flight lines along which the data were taken run NW-SE, therefore, the data can not directly observe NW-SE trending structures.

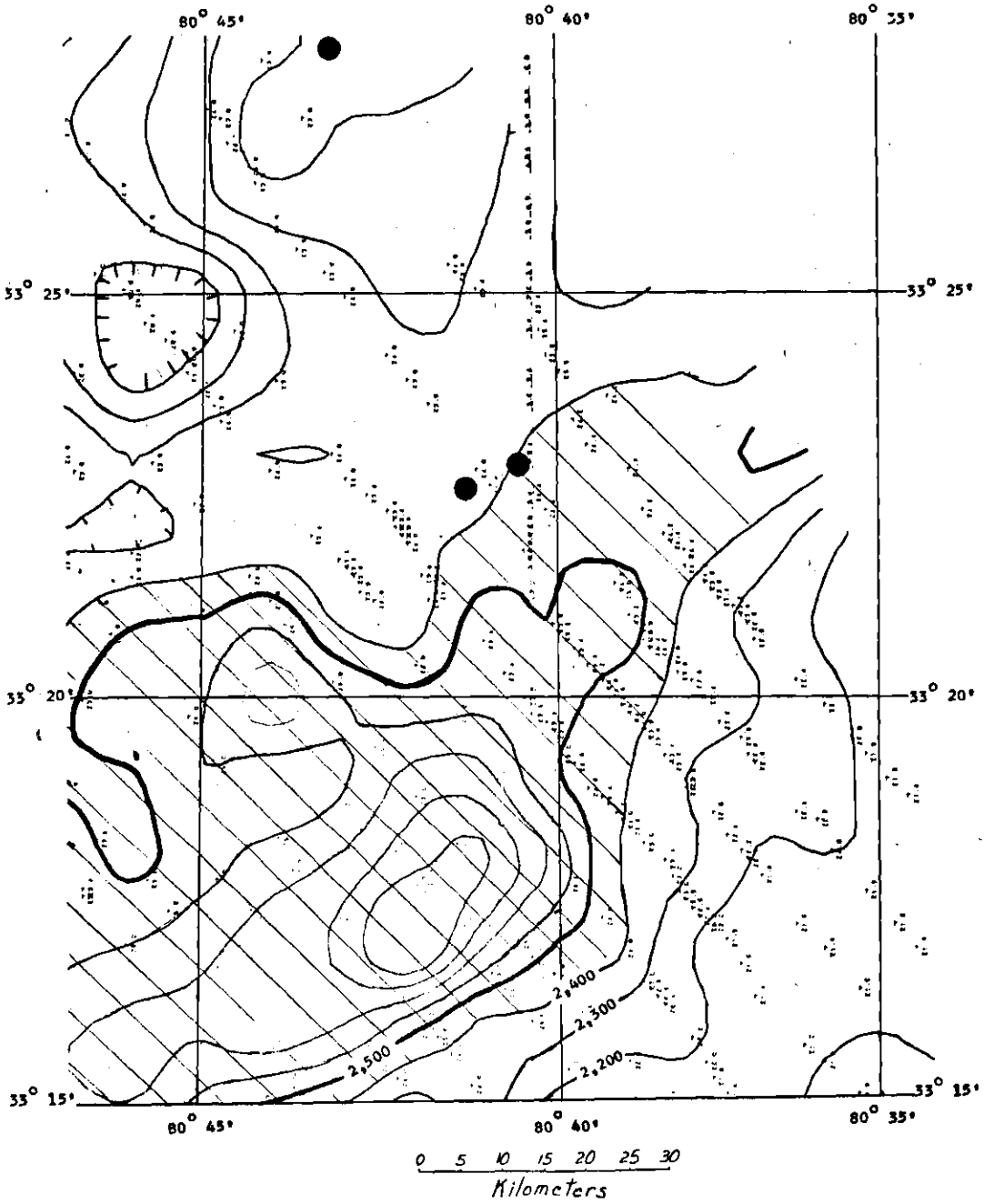


Figure 17. Contour Plot of Aeromagnetic Data Taken from Map of the Savannah River Plant Area. Ridge of Positive Magnetic Values is Crosshatched and Bowman Microearthquake Epicenters are Indicated.

CHAPTER VI

DISCUSSIONS AND CONCLUSIONS

The location of the 1972 February 3, earthquake near Bowman suggests the presence of an active fault and microearthquake reconnaissance data shows a continuing sequence of microearthquake activity in the area.

The epicenters of the 1972 December 16, microearthquake and the 1973 March 22, 14h42m GMT microearthquake are very near each other. The location of the 1973 March 22, 06h42m GMT event, however, is approximately 12 km north of the two other epicenters. The (S-P) time of the 1972 August 8, microearthquake indicates that its epicenter does not agree with either of the previously discussed locations. This indicates either that seismic activity is occurring at several points along a single NW-SE trending fault or that more than one fault is responsible for the microearthquake activity near Bowman.

Another indication that the microearthquakes recorded near Bowman may not share a common origin is the difference in character of the seismograms of the various events. The Meyers Farm record of the 1972 Agusut 8, event exhibits a fairly high amplitude refracted P phase. The record of the 1972 December 16, microearthquake which was recorded on the

same site by a similar instrument, shows a very low amplitude refracted P phase. This implies that the events either did not share a common raypath or that their focal mechanisms differ.

Other evidence indicates that the three located events may have occurred at different depths. The refracted P phase of the 1973 March 22, 14h42m GMT event was greater than or equal to the amplitude of the refracted S phase on all records of this event. This characteristic, unique to the records of the 1973 March 22, 14h42m GMT event, may be indicative of a deeper focal depth. Indeed, the epicenter of this event is most precisely located when a depth of focus of 0.61 km is assumed. The two other events are most precisely located when a focal depth of 0.46 km is used in the travel time computations. However, these depths may be no better than order of magnitude estimates of the actual focal depths.

The data obtained during the microearthquake reconnaissance surveys near Bowman are insufficient to locate a fault plane in the vicinity of Bowman. However, recent seismic activity in areas adjacent to Bowman have served to define more clearly the hypothesized NW-SE trending belt of seismic activity that passes through the Bowman area. Two events were reported felt in Lexington, South Carolina on March 7, 1973, at 08:00 GMT and 11:00 GMT. Portable smoked paper seismographs were operating in Bowman at the time but

the ratio of signal to noise was too small to permit a positive identification of these events. Additional microearthquakes were recorded by a seven station NOAA seismic array which was operating in the coastal region of South Carolina. Events which were recorded and located by the NOAA array in the period from March to July of 1973, have been plotted in Figure 18 (data courtesy of Art Tarr). Other events which were recorded but which could not be located have been omitted. Figure 18 also shows the location of the Bowman and Lexington events which occurred in the interval from March to July of 1973. Whereas the Columbia-Lexington and Summerville-Charleston areas have histories of seismic activity extending over many years, the Bowman area was apparently seismically inactive prior to the 1971 May 19, event and its successors. The linear alignment and close proximity in time of the events plotted in Figure 18 suggests that the events may be related in some manner. Data are insufficient to conclude that these events occurred along a common fault zone but the possibility warrants investigation by future seismic surveys.

The apparent basement velocity of 6.3 km/sec $\pm$ 0.7 km/sec which was obtained from the Carn Farm array data lends support to the basement velocity of 6.9 km/sec which was used in the epicenter location computations for the Bowman microearthquakes. Velocities in the range from 6.1 km/sec to 6.9 km/sec have been measured in diabase

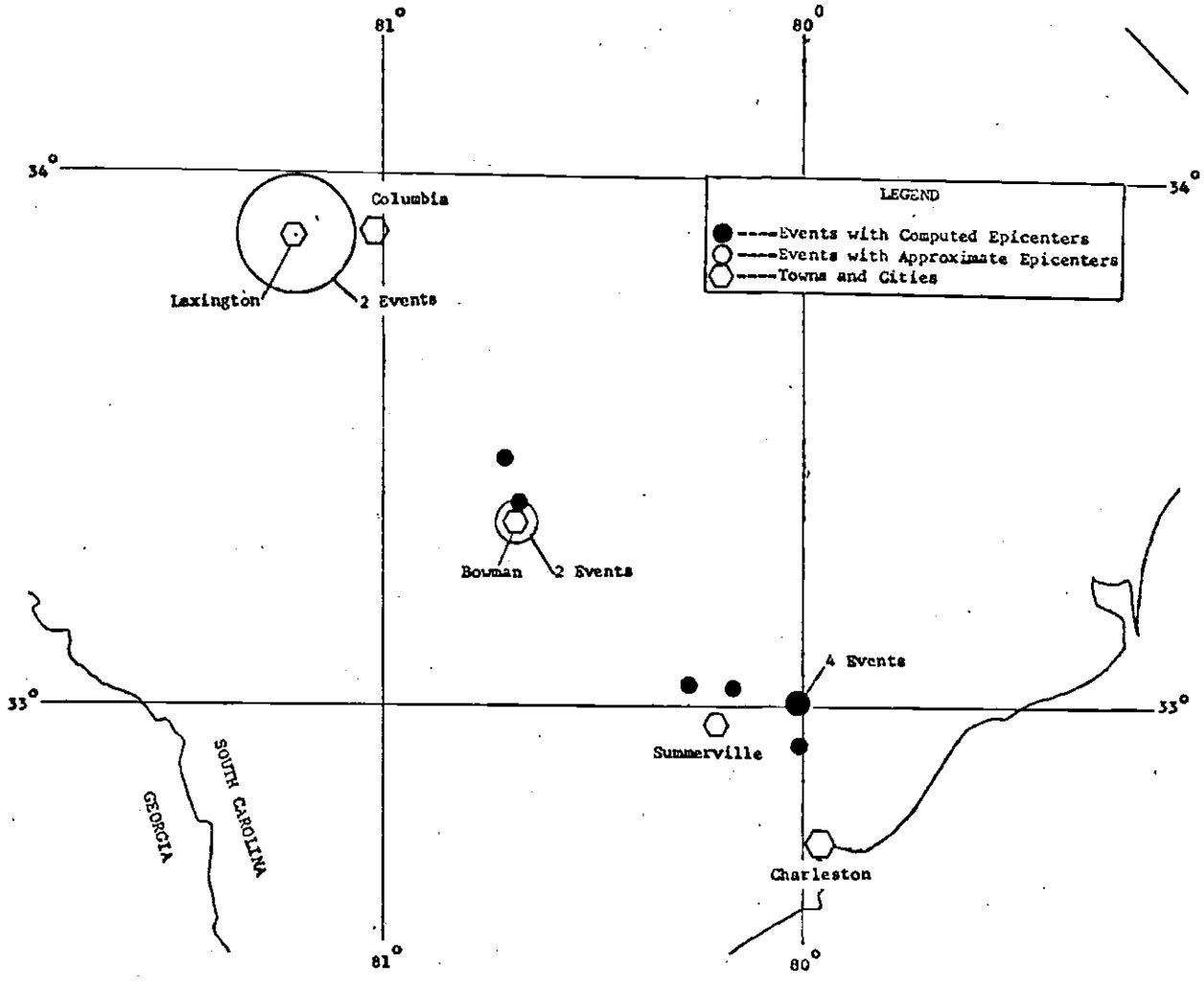


Figure 18. Plot of Bowman and Lexington Events which Occurred from March to July, 1973. Also Included, NOAA Events which Occurred in the Same Time Interval and for which Epicenter Locations were Computed. Size of Open Circles Indicates Uncertainty of Location.

(Anderson and Lieberman, 1966). Seismic refraction work by Pooley (1960) shows that velocities in the range of 6.4 km/sec to 7.0 km/sec have been observed at other locations in the Coastal Plain. Pooley has attributed these high velocities at least in part to the presence of diabase.

The positive linear gravity anomaly suggests that the velocities used in the analysis of the seismic data are appropriate. The linear anomaly that passes through the epicentral region may be the expression of a dense structure at the basement which varies in width from 6 km to 7 km and which extends downward for 10 km to 12 km. Such a structure would explain the high basement velocities that are indicated by the seismic data. The magnetic data which is compatible with the gravity data, also suggests a basement structure composed of material with a greater susceptibility than the surrounding basement material. Diabase appears to be a reasonable material for the basement structure and the presence of such a diabase structure would simultaneously explain both magnetic and gravity anomalies. This possibility will remain unproven until deep well data is obtained for the epicentral region.

The Bouguer profile of the detailed gravity line shows a steep 1.3 mgal jump which can be simulated by a model of a normal fault with a throw of approximately 46 meters. Perturbations in the gravity field of the linear anomaly suggest that the feature responsible for the sharp anomaly in the detailed line strikes NW-SE.

CHAPTER VII

RECOMMENDATIONS

If more microearthquakes were recorded by arrays of seismographs having good time control, the additional seismic data might lead to the successful definition of the fault plane through the Bowman area. Microearthquakes recorded by arrays of sufficient size would also yield much needed focal depth information which would aid in determining the vertical extent of the hypothesized fault. A spectral analysis of the taped records of the 1973 March 22, 14h42m GMT event could possibly yield some information about the focal mechanism of that event. Since events have been reported to the NW and SE of Bowman, it would also be interesting to place portable seismographs between Bowman and these reported events, thus serving to better define the extent and width of the belt of seismic activity which passes through Bowman.

Additional lines of detailed gravity data taken parallel to the first detailed line but displaced to the NW-SE should indicate whether the sharp anomaly is due to an extended feature or to a local perturbation in the subsurface structure. The configuration of the structure could also probably be investigated by carefully executed

refraction lines through the epicentral region and along the axis of the linear anomaly. In addition, high altitude photographs of the Bowman area might serve to locate any faults having surface expression.

APPENDIX I

ANALYSIS OF SEISMIC DATA

The seismic systems used in the microearthquake reconnaissance surveys were Sprengnether portable smoked paper seismographs, two of which were on loan from Virginia Polytechnical Institute, courtesy of Dr. Gilbert Bollinger. Two types of geophones were used with the recorders. When possible, a Hall-Sears HS10-1A 1 Hz geophone was used, but in a few cases an array of 15 Hz exploration geophones was used. Typically, the systems were operated with voltage gains of from 1,000 to 25,000. At 30 Hz, displacement gains generally ranged from 50 k to 100 k at night but these had to be reduced to 25 k to 80 k during the noisier daylight hours. System response curves for the combination 1 Hz geophone and amplifier system and 15 Hz exploration geophone and amplifier system were developed using the technique of Espinose, et al. (1962). The acceleration response curves and particle velocity curves for the systems are plotted in Figure 19.

Smoked paper records of microearthquakes were contact printed on 35 mm film and then enlarged by a factor of 15 with a microfilm printer. This permitted a more accurate measure of (S-P) times than is generally practical from the

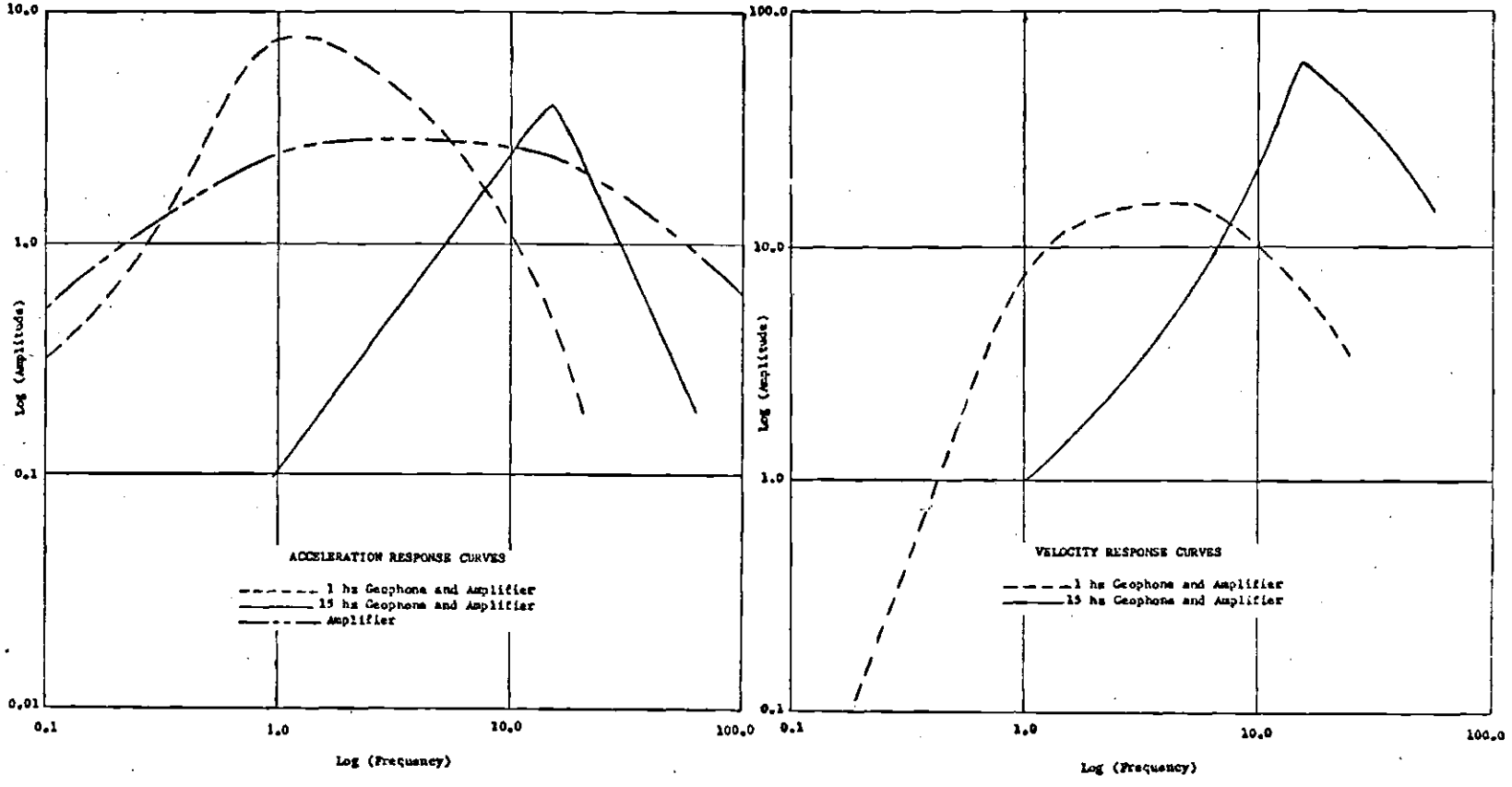


Figure 19. Acceleration Response Curves for the 1 Hz Geophone and Amplifier System, the 15 Hz Geophone and Amplifier System, and the Amplifier. Particle Velocity Curves for the Two Geophone and Amplifier Systems.

original seismograms. For location of the events, standard time-distance relations were used to compute a theoretical (S-P) time for a given epicenter location. This was done for all stations which recorded the event and a total standard deviation was computed based on the deviation of the observed (S-P) time for each recording station. A grid of epicenter locations was projected over the epicentral area and a total standard deviation value was computed for each grid location. Grid intervals of 1 km E-W and 0.3 km N-S were used. The epicenter choice representing the smallest total standard deviation of theoretical (S-P) times from observed (S-P) times could be chosen to a precision of less than one grid interval. Confidence ellipses which were derived from the printed grid values were used to determine the precision of each microearthquake epicenter location. All the computations were performed by a fortran program "Error Grid." The epicenters plotted in Figures 5 and 7 are the locations calculated by the "Error Grid" program. A printout of "Error Grid" is provided in this appendix.

A fortran program "Do-All," which was developed by Dr. L. T. Long to compute the location of Southeastern earthquakes, was modified to provide a check for the "Error-Grid" locations of the Bowman microearthquakes. The program was written to employ the technique of Wiggins (1972) to find an origin time and epicenter corresponding to the least mean squares fit of the observed travel times to theoretical

travel times. The least mean squares technique requires an initial guess with a small error. The location computed by "Error Grid" was used as the first guess for the "Do-All" program. If the location computed by "Do-All" was very near the "Error Grid" location and the adjustment to the origin time computed by "Do-All" was small, this was accepted as a confirmation of the "Error Grid" epicenter location. A printout of the "Do-All" program is included in this appendix.

Printout of the "Error Grid" Program

```
C*****THIS PROGRAM CAUSES THE ERROR SUBROUTINE TO PRINT OUT AN ERROR
C*****MATRIX FOR SEVERAL DIFFERENT POSSIBLE FOCAL DEPTHS.  DATA FORMAT
C*****SAME AS FOR DO-ALL.
      DIMENSION DEPTH(3)
      COMMON IPH(20),Q(20),ID(20)
      DATA DEPTH/0.0,.229,.457/
C*****IPH=PHASE,  XZ=FOCAL DEPTH,  ID=STATION IDENTIFICATION NUMBER
      N=1
    4 READ(5,102) IPH(N),Q(N),SI,EZ,ID(N)
  102 FORMAT(2X,I1,2(2X,F7.3),2X,F5.3,2X,I1)
      IF(IPH(N).EQ.0) GO TO 5
      N=N+1
      GO TO 4
    5 CONTINUE
      DO 6 I=1,3
       EZ=DEPTH(I)
    6 CALL ERROR(EZ,N)
      STOP
      END



C*****SUBROUTINE ERROR PRINTS OUT A ERROR GRID FOR EARTHQUAKE EPICENTER
C*****LOCATIONS.  GRID APPROXIMATELY TO THE SCALE OF A 15 MIN. QUAD. MAP.
      SUBROUTINE ERROR(EZ,N)
      DIMENSION SLAT(4),SLONG(4),ER(500)
      COMMON IPH(20),Q(20),ID(20)
C*****SLAT AND SLONG ARE THE LATITUDE AND LONGITUDE OF RECORDING STATIONS
      DATA SLAT/33.4083,33.3985,33.3630,33.3350/,SLONG/80.6263,
     C80.7092,80.6890,80.6572/
      I=0
      SDELP=0
      SDELS=0
C*****ELA AND ELO ARE THE TOP LEFT COORDINATES OF THE GRID.
      ELA=33.4333
      ELO=80.7167
C*****XINCA AND XINCO ARE THE GRID INCREMENTS.
      XINCA=0.002417
      XINCO=0.01045
      WRITE(6,91)
   91 FORMAT(1H1,29X,'EARTHQUAKE LOCATION ERROR GRID')
      WRITE(6,92)
   92 FORMAT(/23X,'GRID COORDINATES, LONG: 80 43MIN---80 38MIN')
      WRITE(6,93)
   93 FORMAT(41X,'LAT:  33 26MIN---33 19MIN')
      WRITE(6,94) EZ
  94  FORMAT(23X,'DEPTH OF FOCUS=',F6.3)
      DO 1  LA=0,48
      DO 1  LO=0,8
      ELAT=ELA-LA*XINCA
      ELONG=ELO-LO*XINCO
      DO 101 NN=1,N
      II=ID(NN)
      A=((ELAT-SLAT(II))*111.11)
      B=((ELONG-SLONG(II))*111.11*0.835)
      D=A**2+B**2
      R=SQRT(D)
      IF(IPH(NN).EQ.5) GO TO 303
C*****EQUATIONS FOR TS AND TP ARE GOOD FOR FOCAL DEPTHS FROM 0 TO .457 KM.
      TP=R*(.146-EZ*0.384+0.349
      DELP=(NN)-TP
      GO TO 101
```

Printout of "Error Grid" (Concluded)

```
303 TS=R*0.253-EZ*0.664+0.606
    DELS=Q(NN)-TS
    SDELP=SDELP+DELP**2
    SDELS=SDELS+DELS**2
101 CONTINUE
304 SUM=(SDELS+SDELP)/N
    SDELP=0
    SDELS=0
    I=I+1
    ER(I)=SQRT(SUM)
    IF(I.EQ.9) GO TO 305
    GO TO 10
305 WRITE(6,90)(ER(II),II=1,9)
    I=0
 90 FORMAT(17X,9F6.3)
 10 CONTINUE
    RETURN
```

Printout of the "Do-All" Program

```
C*****TECHNIQUE TAKEN FROM RALPH A. WIGGINS--THE GENERAL LINEAR IVNERSE
C*****PROBLEM.  REVIEWS OF GEOPHYSICS AND SPACE PHYSICS, FEB. 1972,VOL 10--NO. 1
C*****OBJECT IS TO FIND (TO,ELAT,ELONG,EZ) CORRESPONDING TO LMS FIT OF
C*****THE OBSERVED TO THEORETICAL TRAVELTIMES.
      DIMENSION C(5),DC(14),S(14),A(14,4),W(4),DP(4),FDP(4),STAT(4),
     CPHAS(6),LABEL(8)
C*****DATA LISTS RECORDING STATIONS AND PHASES.
      DATA STAT/3HWGC,3HSHC,3HROW,3HCFM/
     CPHAS/2HPG,1HP,2HPN,2HSG,1HS,2HSN/
C*****DATA READ UNDER STANDARD EARTHQUAKE LIST FORMAT
      READ(5,100) IYR,MO,IDA,IHR,MIN,SEC,ELAT,ELONG,INT,BMAG,
     CIST,IQ,SP,(LABEL(J8),J8=1,8)
  100 FORMAT(I4,4I2,F3.1,2F7.4,I2,F2.1,2I1,A4,8A5)
C*****FOLLOWING CARD READS SOLUTION WEIGHTS
      READ(5,101) WX,WY,WT,WZ
C*****THESE IF STATEMENTS ALLOW INPUT WEIGHTS TO DETERMINE WHETHER THE COMPUTED
C*****MATRIX IS 4X4, 3X3, OR 2X2.
      IF(WT.LT.0.0001) GO TO 22
      M=4
      GO TO 23
   22 M=3
      IF(WZ.LT.0.0001) M=2
   23 CONTINUE
  101 FORMAT(2X,4F8.3)
      TO=IHR*3600.+MIN*60.+SEC
    4 N=0
      WRITE(6,105)MO,IDA,IYR,IHR,MIN,SEC,ELAT,ELONG,(LABEL(J8),J8=1,8)
  105 FORMAT(2X,I2,1H/,I2,1H/,I4/,4H  H=,I2,2X,I2,2X,F4.1/,6H  LAT=,
     C F7.3/,7H  LONG=,F7.3/,2X,A4,8A5//)
      WRITE(6,200) WX,WY,WT,WZ
  200 FORMAT(/2X,'WX=',F8.3,'WY=',F8.3,'WT=',F8.3,'WZ=',F8.3///)
      WRITE(6,106)
  106 FORMAT(5X,'STATION',5X,'PHASE',5X,'ARRIVAL TIME')
C*****IPH=PHASE IDENTIFICATION, Q=PHASE TIME, SI=DATA WEIGHT, EZ=DEPTH OF FOCUS,
C*****ID=STATION IDENTIFICATION
    6 READ(5,102,END=5) IPH,Q,SI,EZ,ID
  102 FORMAT(2X,I1,2(2X,F7.3),2X,F5.3,2X,I1)
      WRITE(6,107) STAT(ID),PHAS(IPH),Q
  107 FORMAT(////7X,A3,8X,A2,9X,F7.1/)
      IF(ID.LT.1) GO TO 5
      N=N+1
      CALL ATIME(IPH,TO,ID,ELAT,ELONG,EZ,C)
      DC(N)=Q-C(1)
      A(N,1)=C(3)
      A(N,2)=C(4)
      A(N,3)=C(2)
      A(N,4)=C(5)
      S(N)=1.0/SQRT(SI)
      GO TO 6
    5 W(1)=SQRT(WX)
      W(2)=SQRT(WY)
      W(3)=SQRT(WT)
      W(4)=SQRT(WZ)
      CALL MAMAN(A,DC,S,W,N,DP,M)
      DO 14 I6=1,4
   14 FDP(I6)=DP(I6)*W(I6)
      TO=TO+FDP(3)
      ELAT=ELAT+FDP(1)/111.11
      ELONG=ELONG+FDP(2)/111.11
      EZ=EZ+FDP(4)
      WRITE(6,108) TO,ELAT,ELONG,EZ
  108 FORMAT(1H1,'RESULTS ARE:',2X,'TO=',F8.2,2X,'ELAT=',F9.4,2X,
     C'ELONG=',F9.4,2X,'EZ=',F6.3)
      STOP
      END
```

Printout of "Do-All" (Continued)

```
      SUBROUTINE ATIME(IPH,TO,ID,ELAT,ELONG,EZ,C)
      DIMENSION C(5),SLAT(4),SLONG(4)
C*****DATA IS LATITUDE AND LONGITUDE OF RECORDING STATIONS
      DATA SLAT/33.4083,33.3985,33.3630,33.3350/,SLONG/80.6263,
     C80.7092,80.6890,80.6572/
      CALL CXY(ELONG,ELAT,SLAT(ID),SLONG(ID),A,B)
      D=A**2+B**2
      R=SQRT(D)
      IF(IPH.EQ.5) GO TO 303
C*****C(1)=THEORETICAL ARRIVAL TIME OF P PHASE DERIVED FROM TRAVEL TIME CURVES
      C(1)=TO+R*(0.146)-EZ*(0.384)+0.349
      C(2)=1.0
      C(3)=(((ELAT-SLAT(ID))*111.11)*0.146)/R
      C(4)=(((ELONG-SLONG(ID))*111.11)*0.146*0.835)/R
C*****0.835=COS(33.6)---LATITUDE CORRECTION
      C(5)=-0.384
      GO TO 304
C*****C(1)=THEORETICAL ARRIVAL TIME OF S PHASE
  303 C(1)=TO+R*(0.255)-EZ*(0.664)+0.606
      C(2)=1.0
      C(3)=(((ELAT-SLAT(ID))*111.11)*0.253)/R
      C(4)=(((ELONG-SLONG(ID))*111.11)*0.253*0.835)/R
      C(5)=-0.664
  304 WRITE(6,305) SLAT(ID),SLONG(ID),R
      WRITE(6,301)
  305 FORMAT(2X,'STATION LATITUDE=',F7.4,2X,'STATION LONGITUDE=',
     CF7.4,2X,'DIST.=',F5.2)
  301 FORMAT(2X,'     C(1)        C(2)        C(3)        C(4)        C(5)')
      WRITE(6,302)(C(IO),IO=1,5)
  302 FORMAT(2X,F11.3,4(3X,F8.3))
      RETURN
      END


      SUBROUTINE CXY(XO,YO,ALAT,ALONG,X,Y)
C*****(XO,YO) IS ORIGIN IN DEGREES<500KMFROM DATA FOR < .1KM ERROR
C*****(ALAT,ALONG) LATITUDE AND LONGITUDE OF DATA POINTS
C*****FROM RICHTER-ELEN SEIS-USING CLARKE SPHEROID
      DIMENSION  B(70), AC(70)
      DATA (B(I),I=30,39)/1.847495,1.8477e1,1.848073,1.848372,
     C1.848673,1.848980,1.849290,1.849605,1.849922,1.850242/
     C(AC(I),I=30,39)/1.856937,1.857033,1.857132,1.857231,1.857331,
     C1.857435,1.857538,1.857643,1.857750,1.857858/
      DLAT=ALAT-YO
      DLONG=ALONG-XO
      IA=(YO+ALAT)/2.0
      AA=(AC(IA)+(AC(IA+1)-AC(IA))*((YO+ALAT)/2.0-IA))
      AA=AA*60.0*COS(0.0174533*ALAT)
      X=AA*DLONG
      BB=(B(IA)+(B(IA+1)-B(IA))*((YO+ALAT)/2.0-IA))*60.0
      Y=BB*DLAT
      RETURN
      END

      SUBROUTINE MINVRT(A,X,NN,MM)
C*****MATRIX INVERSION SUBROUTINE, A IS THE INPUT MATRIX, X IS THE OUTPUT
 C****MM=NN+1
      DIMENSION A(5,5),X(4,4)
    8 DO 9 I=1,NN
      DO 9 J=1,NN
    9 A(I,J)=X(I,J)
      DO 16 N=1,NN
      A(N,MM)=1.
      DO 10 I=2,NN
   10 A(I,MM)=0.
      DO 11 J=1,NN
   11 A(NN,J)=A(1,J+1)/A(1,1)
      DO 12 I=2,NN
      XX=A(I,1)
      DO 12 J=1,NN
   12 A(I-1,J)=A(I,J+1)-XX*A(NN,J)
      DO 16 J=1,NN
   16 X(NN,J)=A(NN,J)
      RETURN
```

Printout of "Do-All" (Concluded)

```
      SUBROUTINE MAMAN(A,DC,S,W,N,DP,M)
C*****MAMAN PERFORMS MATRIX COMPUTATIONS
      DIMENSION A(14,4),DC(14),S(14),W(4),AN(14,4),ATA(4,4),AVRT(5,5),
     CATDC(4),DP(4)
      DO 7 I=1,N
      DO 7 J=1,M
    7 AN(I,J)=S(I)*A(I,J)*W(J)
      WRITE(6,201)((AN(IA,JA),IA=1,N),JA=1,4)
  201 FORMAT(1H1,4(1X,F12.2)/)
      DO 8 L=1,4
      DO 8 LL=1,4
    8 ATA(L,LL)=0
      DO 9 I1=1,M
      DO 9 J1=1,M
      DO 9 K1=1,N
    9 ATA(I1,J1)=AN(K1,I1)*AN(K1,J1)+ATA(I1,J1)
      WRITE(6,202) ((ATA(IB,JB),IB=1,4),JB=1,4)
  202 FORMAT(1X///,(4(1X,F12.2)/))
      I1=M+1
      CALL MINVRT(AVRT,ATA,M,M1)
      WRITE(6,203)((AVRT(IC,JC),IC=1,4),JC=1,4)
  203 FORMAT(2X///,(4(1X,F12.2)/))
      DO 10 I2=1,4
   10 ATDC(I2)=0
      DO 11 I3=1,M
      DO 11 K3=1,N
   11 ATDC(I3)=AN(K3,I3)*DC(K3)*S(K3)+ATDC(I3)
      WRITE(6,204)(ATDC(IE),IE=1,4)
  204 FORMAT(2X///,(4(1X,F12.2)/))
      DO 12 I4=1,4
   12 DP(I4)=0
      DO 13 I5=1,M
      DO 13 J5=1,M
   13 DP(I5)=AVRT(I5,J5)*ATDC(J5)+DP(I5)
      WRITE(6,205)(DP(IG),IG=1,4)
  205 FORMAT(2X///,(4(1X,F12.2)/))
      RETURN
      END
```

APPENDIX II

ANALYSIS OF GRAVITY AND MAGNETIC DATA

The gravity data were taken with a North American Geophysical Company gravity meter model AG-1, number 68. This meter can be read to a precision of approximately ±0.01 mgals. Traverses were closed at least once every six hours, the drift usually being of the order of 0.05 mgal/hr. The Bowman 15 minute Quadrangle map (USGS) which has 10 ft contour intervals provided the elevation data.

Relative latitude errors between scattered stations were responsible for location errors which were certainly less than ±0.19 km so that the maximum deviation that can be attributed to such errors is 0.14 mgal. Station elevations obtained from the Bowman Quadrangle map were probably in error by a maximum of ±2.0 meters so that the maximum gravity deviation due to elevation errors is 0.3 mgal.

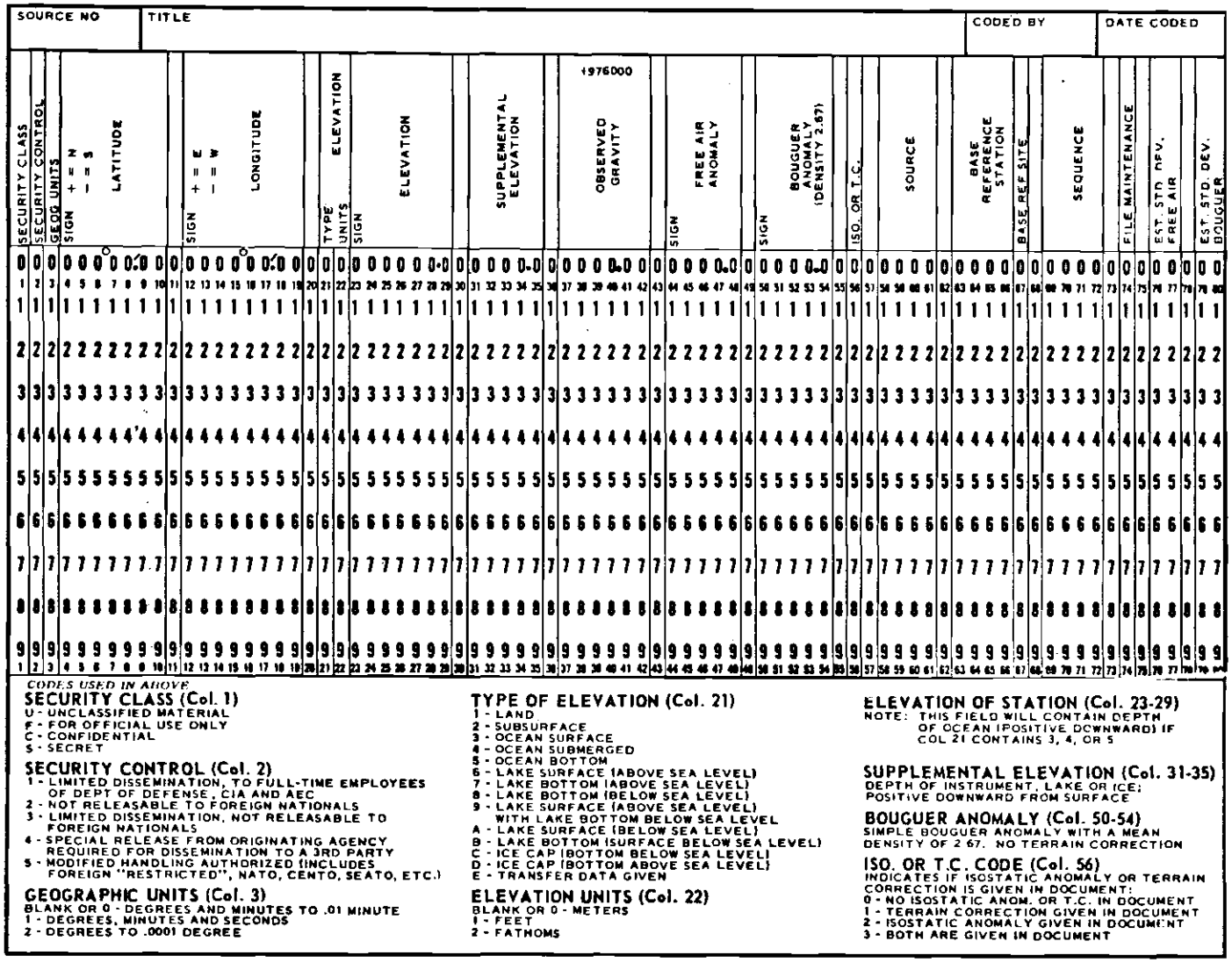
Two base stations were used in the gravity surveys. The state base station at Vance was used to establish a base station at Walnut Grove Church. Two gravity meters were used to relate Walnut Grove Church to Vance, South Carolina. This precaution insured a precision of ±0.02 mgal.

During the Bouguer correction to the gravity, a density of 2.67 gm/cc was assumed. The simple Bouguer

gravity values were plotted and contoured on a Calcomp Plotter by the General Purpose Contouring Program (California Computer Products, Inc., 1968). The contouring program used the eight nearest data points to compute grid values. Grid intervals were chosen commensurate with the density of the gravity data. A listing of the newly acquired gravity data for the Bowman, South Carolina area is included in this appendix.

Theoretical gravity profiles were computed by a program which used the technique of Talwani, Wortzel and Landisman (1959). The program, "GPROF", computed and plotted the theoretical gravity profile of two dimensional models. A printout of "GPROF" is listed in this appendix.

Aeromagnetic data were taken directly from the Geological Survey map of the Savannah River Plant area (Petty et al., 1965). The data were plotted and contoured by the General Purpose Contouring Program in the same way as the gravity data.



Format (Standard DOD) of Gravity Data

List of Gravity Data

332453	-	803799	1	496	3616094	1615	1173	GT41	GA 1	18	1
332620	-	802543	1	396	3615219	1293	851	GT23	GA 1	1	1
332519	-	803045	1	372	3616078	1442	1027	GT23	GA 1	2	6
332500	-	803047	1	366	3617367	1496	1048	GT23	GA 1	3	6
332601	-	803086	1	366	3614343	1540	1132	GT23	GA 1	4	6
332651	-	803076	1	369	3611422	1638	1223	GT23	GA 1	5	6
332683	-	803094	1	372	3611133	1719	1304	GT23	GA 1	6	6
332700	-	803130	1	372	3612946	1760	1345	GT23	GA 1	7	6
332793	-	803169	1	436	3612992	1996	1460	GT23	GA 1	8	3
332875	-	803215	1	472	3614133	1963	1436	GT23	GA 1	9	3
332910	-	803229	1	472	3613938	1990	1472	GT23	GA 1	10	6
332945	-	803271	1	503	3610930	2144	1593	GT23	GA 1	11	3
332994	-	803285	1	521	3615750	1996	1526	GT23	GA 1	12	6
333041	-	803292	1	453	3617430	2050	1561	GT23	GA 1	13	6
333071	-	803296	1	472	3617766	2159	1631	GT23	GA 1	14	1
333104	-	803336	1	472	3617117	2048	1521	GT23	GA 1	15	6
333140	-	803362	1	457	3616764	1912	1402	GT23	GA 1	16	6
333176	-	803421	1	494	3615305	1305	1284	GT23	GA 1	17	6
333205	-	803456	1	518	3615219	1359	1281	GT23	GA 1	18	6
333238	-	803479	1	524	3615139	1822	1237	GT23	GA 1	19	6
333273	-	803518	1	533	3614594	1751	1156	GT23	GA 1	20	1
333299	-	803559	1	518	3614816	1609	1031	GT23	GA 1	21	6
333331	-	803618	1	488	3623750	1444	900	GT23	GA 1	22	6
333366	-	803655	1	506	3623414	1415	851	GT23	GA 1	23	1
333421	-	803696	1	494	3621406	1104	553	GT23	GA 1	24	6
333461	-	803749	1	552	3619510	1046	421	GT23	GA 1	25	3
333502	-	803758	1	555	3613617	900	281	GT23	GA 1	26	1
333552	-	803826	1	555	3617898	788	169	GT23	GA 1	27	6
333505	-	803905	1	488	3616595	497-	47	GT23	GA 1	28	6
332599	-	802564	1	402	3615219	1339	890	GT24	GA 2	2	6
332622	-	802639	1	402	3615930	1379	930	GT24	GA 2	3	6
332595	-	802684	1	402	3615930	1416	967	GT24	GA 2	4	6
332578	-	802721	1	390	3615813	1390	955	GT24	GA 2	5	6
332560	-	802725	1	381	3616031	1409	984	GT24	GA 2	6	6
332551	-	802856	1	375	3616438	1443	1025	GT24	GA 2	7	6
332552	-	802905	1	369	3616430	1425	1013	GT24	GA 2	8	3
332553	-	802965	1	381	3616531	1473	1048	GT24	GA 2	9	6
332524	-	803029	1	372	3616086	1437	1022	GT24	GA 2	10	6
332489	-	803068	1	357	3615891	1417	1019	GT24	GA 2	11	6
332453	-	803125	1	335	3615628	1389	1015	GT24	GA 2	12	6
332443	-	803154	1	335	3615509	1395	1021	GT24	GA 2	13	6
332405	-	803190	1	351	3614406	1366	975	GT24	GA 2	14	6
332360	-	803254	1	351	3613141	1303	912	GT24	GA 2	15	6
332318	-	803295	1	351	3612133	1259	868	GT24	GA 2	16	6
332269	-	803315	1	332	3610281	1063	692	GT24	GA 2	17	3
332195	-	803343	1	305	3609148	977	637	GT24	GA 2	18	6
332163	-	803395	1	296	3608461	919	590	GT24	GA 2	19	6
332146	-	803442	1	293	3608172	907	580	GT24	GA 2	20	1
332113	-	803489	1	326	3607547	974	610	GT24	GA 2	21	6
332150	-	803535	1	335	3608188	1045	661	GT24	GA 2	23	6
332132	-	803599	1	335	3608250	1083	689	GT24	GA 2	24	6
332112	-	803735	1	366	3609539	1221	813	GT24	GA 2	25	6
332127	-	803829	1	369	3609656	1335	924	GT24	GA 2	26	6
332134	-	803869	1	369	3611481	1083	1071	GT24	GA 2	27	6
332149	-	803929	1	358	3612195	1367	1024	GT24	GA 2	28	6
332686	-	804015	1	467	3610539	1695	1179	GT24	GA 2	31	6
333359	-	804279	1	549	3609789	197-	415	GT24	GA 2	33	1
333329	-	804241	1	563	3610711	175-	366	GT24	GA 2	34	6
333282	-	804203	1	491	3611059	333-	214	GT24	GA 2	35	6
333249	-	804179	1	500	3612214	443-	115	GT24	GA 2	36	6
333215	-	804143	1	427	3614430	484	8	GT24	GA 2	37	6
333188	-	804122	1	515	3612865	633	58	GT24	GA 2	38	3
333133	-	804065	1	488	3614219	758	214	GT24	GA 2	39	6
333089	-	804041	1	485	3615164	911	371	GT24	GA 2	40	6
333065	-	804016	1	463	3615977	959	443	GT24	GA 2	41	6
333022	-	803982	1	424	3617985	1043	621	GT24	GA 2	42	6
332965	-	803945	1	491	3616547	1249	692	GT24	GA 2	43	6
332933	-	803900	1	482	3616710	1267	729	GT24	GA 2	44	6
33289	-	803880	1	488	3616438	1323	779	GT24	GA 2	45	6
332850	-	803841	1	485	3616031	1419	778	GT24	GA 2	46	6

Gravity Data (Continued)

332810	803796	1	460	3615625	1298	765	GT24	GA	2	47	6
332750	803745	1	457	3615169	1296	778	GT24	GA	2	48	3
332700	803725	1	449	3614750	1298	784	GT24	GA	2	49	6
332650	803714	1	446	3614273	1296	832	GT24	GA	2	50	6
332607	803675	1	437	3613791	1453	959	GT24	GA	2	51	6
332557	803645	1	437	3613491	1451	1352	GT24	GA	2	52	6
332549	803594	1	415	3613195	1943	1481	GT24	GA	2	53	6
332521	803569	1	396	3612939	1912	1473	GT24	GA	2	54	6
332491	803465	1	390	3614453	1475	1440	GT24	GA	2	55	6
332471	803429	1	392	3614253	1752	1347	GT24	GA	2	56	6
332435	803379	1	396	3616430	1650	1215	GT24	GA	2	57	6
332409	803346	1	396	3615000	1468	1060	GT24	GA	2	58	6
332606	802485	1	405	3615102	1328	876	GT26	GA	3	2	6
332574	802415	1	418	3614539	1319	863	GT26	GA	3	3	6
332565	802372	1	397	3613689	1305	866	GT26	GA	3	4	6
332551	802298	1	378	3614906	1299	878	GT26	GA	3	5	1
332541	802252	1	369	3615016	1297	885	GT26	GA	3	6	6
332501	802208	1	363	3614604	1291	887	GT26	GA	3	7	6
332491	802138	1	355	3614080	1289	855	GT26	GA	3	8	1
332385	803315	1	365	3614445	1426	1025	GT26	GA	3	9	6
332341	803229	1	335	3612477	1217	843	GT26	GA	3	10	6
332302	803175	1	365	3612539	1180	840	GT26	GA	3	11	6
332291	803150	1	299	3612086	1152	799	GT26	GA	3	12	6
332295	803085	1	365	3611523	1089	749	GT26	GA	3	13	6
332281	803015	1	308	3610734	1059	696	GT26	GA	3	14	6
332262	802972	1	302	3610750	1047	710	GT26	GA	3	15	6
332291	802895	1	311	3609616	913	566	GT26	GA	3	16	6
332071	804159	1	451	3609880	1662	1159	GT26	GA	3	17	6
332045	804157	1	442	3609305	1651	1138	GT26	GA	3	18	6
332013	804185	1	454	3608683	1658	1151	GT26	GA	3	19	6
331995	804224	1	451	3607992	1629	1126	GT26	GA	3	20	3
331941	804260	1	445	3607133	1571	1075	GT26	GA	3	21	3
331961	804247	1	462	3606078	1486	973	GT26	GA	3	22	6
332425	803796	1	395	3616462	1706	1270	GT31	GA	1	2	3
332335	803809	1	411	3614851	1694	1235	GT31	GA	1	3	6
332177	803731	1	393	3608969	1370	831	GT31	GA	1	8	6
332223	803736	1	402	3611124	1450	1001	GT31	GA	1	9	3
332279	803694	1	396	3612930	1515	1080	GT31	GA	1	10	6
332336	803712	1	384	3615773	1699	1271	GT31	GA	1	11	3
332463	803786	1	396	3615398	1556	1114	GT31	GA	1	12	6
332505	803818	1	424	3613031	1314	842	GT31	GA	1	13	6
332542	803854	1	454	3612484	1305	798	GT32	GA	1	2	6
332592	803824	1	463	3611559	1150	633	GT32	GA	1	3	6
332621	803842	1	469	3611188	1116	592	GT32	GA	1	4	6
332693	803928	1	486	3612914	1173	653	GT32	GA	1	5	3
332734	803959	1	475	3613320	1158	658	GT32	GA	1	6	3
332512	803879	1	451	3611552	1223	720	GT32	GA	1	7	6
332479	803876	1	463	3612451	1398	882	GT32	GA	1	8	3
332572	803961	1	472	3609914	1063	536	GT33	GA	1	2	3
332515	803942	1	488	3610567	1233	689	GT33	GA	1	4	6
332395	804042	1	463	3609587	1145	629	GT33	GA	1	5	6
332372	803961	1	457	3610560	1350	840	GT33	GA	1	6	6
332346	803906	1	442	3612102	1499	1006	GT33	GA	1	7	6
332383	803869	1	427	3612477	1439	963	GT33	GA	1	8	6
332401	804104	1	463	3606273	907	390	GT33	GA	1	9	6
332399	804204	1	463	3606030	931	414	GT33	GA	1	10	3
332467	804261	1	500	3605922	893	335	GT33	GA	1	11	3
332524	804251	1	521	3606297	919	337	GT33	GA	1	12	3
332398	803815	1	396	3614977	1574	1132	GT34	GA	1	2	6
332425	803846	1	396	3614320	1474	1032	GT34	GA	1	3	6
332696	804156	1	521	3609141	962	380	GT34	GA	1	4	3
332747	804196	1	494	3607852	680	129	GT34	GA	1	5	3
332679	804132	1	506	3606422	670	106	GT34	GA	1	6	3
332614	804036	1	506	3605773	695	151	GT34	GA	1	7	3
332509	803838	1	427	3612538	1407	1331	GT35	GA	1	2	3
332492	803855	1	406	3612258	1370	1448	GT35	GA	1	3	3
332437	803847	1	408	3611417	1805	1348	GT35	GA	1	4	6
332503	803855	1	442	3610313	1387	1394	GT35	GA	1	5	6
332721	803839	1	463	3610394	1797	1273	GT35	GA	1	6	3
331997	803656	1	366	3607586	894	406	GT37	GA	1	2	3

Gravity Data (Continued)

331945	803550	1	357	3610938	671	273	GT37	GA	1	3	3
331859	803550	1	363	3609211	534	133	GT37	GA	1	4	3
331907	803547	1	369	3609368	659	248	GT37	GA	1	5	3
331751	803745	1	381	3607769	579	198	GT37	GA	1	6	3
331895	803749	1	373	3609041	873	452	GT37	GA	1	7	3
331917	803924	1	421	3610436	1259	790	GT37	GA	1	8	3
331969	803960	1	424	3610436	1508	1136	GT37	GA	1	9	3
332057	804045	1	435	3611568	1526	1174	GT37	GA	1	10	3
332015	803925	1	418	3609211	1491	1025	GT38	GA	1	3	3
332035	803941	1	394	3609102	1294	960	GT38	GA	1	4	3
331965	804000	1	436	3609859	1676	1192	GT38	GA	1	5	3
331902	803996	1	421	3609533	1500	1050	GT38	GA	1	6	3
331827	803974	1	415	3608125	1234	772	GT38	GA	1	7	3
331779	803962	1	402	3607438	1268	819	GT38	GA	1	8	3
331712	803962	1	405	3597099	841	389	GT38	GA	1	9	3
332136	804094	1	376	3611753	1555	1133	GT38	GA	1	10	3
332212	804050	1	421	3611648	1576	1107	GT38	GA	1	11	3
332319	804341	1	466	3606146	1016	496	GT39	GA	1	2	3
332367	804402	1	497	3605383	940	386	GT39	GA	1	3	3
332460	804469	1	515	3604266	883	309	GT39	GA	1	4	3
332519	804548	1	521	3602930	600	18	GT39	GA	1	5	3
332604	804170	1	491	3608639	936	389	GT39	GA	1	6	3
332666	803964	1	515	3608063	850	306	GT39	GA	1	8	3
332303	804170	1	463	3607258	1139	622	GT39	GA	1	9	6
332292	804100	1	475	3608477	1314	784	GT39	GA	1	10	3
332240	803999	1	439	3611609	1567	1098	GT40	GA	1	2	3
332165	804176	1	399	3610359	1443	998	GT40	GA	1	3	3
332169	804241	1	454	3608023	1373	867	GT40	GA	1	4	3
332186	804322	1	469	3606969	1292	769	GT40	GA	1	5	3
332227	804395	1	491	3606750	1079	532	GT40	GA	1	6	3
332163	804445	1	482	3603505	994	457	GT40	GA	1	7	3
332086	804200	1	448	3606758	1542	1042	GT40	GA	1	8	3
332084	804313	1	463	3607156	1452	915	GT40	GA	1	9	3
331875	804372	1	448	3605320	1490	991	GT40	GA	1	10	3
331819	804257	1	424	3606461	1618	1145	GT40	GA	1	11	3
331817	804076	1	430	3606867	1668	1188	GT40	GA	1	12	3
332008	803595	1	351	3603414	816	425	GT40	GA	1	13	3
331982	803467	1	335	3601789	642	268	GT40	GA	1	14	3
331922	803427	1	332	3600211	557	187	GT40	GA	1	15	3
331822	803419	1	332	3597641	438	67	GT40	GA	1	16	3
331760	803300	1	302	3597172	383	46	GT40	GA	1	17	3
332234	803915	1	430	3611719	1578	1098	GT41	GA	1	5	6
332279	803940	1	460	3611576	1596	1083	GT41	GA	1	6	6
332296	803941	1	460	3611391	1553	1040	GT41	GA	1	7	6
332326	803937	1	458	3611297	1494	987	GT41	GA	1	8	6
332293	803975	1	446	3611063	1487	988	GT41	GA	1	9	6
332306	803995	1	457	3610894	1402	892	GT41	GA	1	10	6
332318	804119	1	457	3609641	1340	830	GT41	GA	1	11	6
332344	804129	1	465	3609102	1259	745	GT41	GA	1	12	6
332365	804051	1	463	3608602	1190	673	GT41	GA	1	13	6
332319	804092	1	457	3608570	1243	723	GT41	GA	1	14	3
332291	804136	1	466	3607164	1256	735	GT41	GA	1	15	6
332363	804159	1	457	3606523	965	455	GT41	GA	1	16	6
332399	804119	1	457	3607273	991	481	GT41	GA	1	17	6
332219	803952	1	427	3611742	1591	1115	GT42	GA	1	2	3
332251	804074	1	427	3610320	1407	931	GT42	GA	1	3	3
332263	804097	1	457	3609273	1378	858	GT42	GA	1	4	3
332345	804071	1	475	3607258	1217	686	GT42	GA	1	5	6
332393	804052	1	472	3608172	1128	601	GT42	GA	1	6	6
332421	804128	1	479	3607586	1058	524	GT42	GA	1	7	6
332440	804099	1	457	3607391	987	477	GT42	GA	1	8	3
332457	804058	1	468	3607992	1087	543	GT42	GA	1	9	3
332459	804015	1	497	3608211	1123	569	GT42	GA	1	10	6
332293	803715	1	436	3613234	1649	1170	GT42	GA	1	11	3
332284	803745	1	424	3613367	1508	1136	GT42	GA	1	12	6
332195	803572	1	341	3609695	1157	776	GT43	GA	1	2	3
332248	803641	1	375	3610906	1309	990	GT43	GA	1	3	6
332043	803893	1	411	3605916	798	451	GT43	GA	1	4	6
332074	803953	1	395	3606102	845	505	GT43	GA	1	5	6
332105	80395	1	326	3606056	934	570	GT43	GA	1	6	3

Gravity Data (Continued)

332124	- 803567	1	429	3617397	989	621	GT45	GA	1	7	6
332139	- 803578	1	335	3613394	1050	666	GT45	GA	1	8	6
332151	- 803589	1	339	3609494	1057	686	GT45	GA	1	9	3
332145	- 803596	1	323	3607736	1130	677	GT45	GA	1	10	6
332102	- 803760	1	335	3607805	1177	703	GT45	GA	1	11	3
332057	- 803691	1	345	3608773	942	662	GT45	GA	1	13	3
332023	- 803740	1	351	3615436	1090	649	GT45	GA	1	14	3
332023	- 803776	1	351	3609846	1174	713	GT45	GA	1	15	6
332141	- 803351	1	399	3609853	1447	982	GT45	GA	1	16	6
332181	- 803649	1	421	3612529	1530	1030	GT45	GA	1	17	6
332195	- 803882	1	427	3603992	1447	971	GT45	GA	1	18	3
332231	- 803952	1	427	3611242	1525	1049	GT45	GA	1	19	3
332107	- 803913	1	363	3611644	1559	1155	GT45	GA	1	20	6
332241	- 804216	1	442	3609586	1436	943	GT44	GA	1	2	6
332261	- 804203	1	396	3609727	1138	696	GT44	GA	1	3	3
332323	- 804235	1	457	3606063	1034	624	GT44	GA	1	4	3
332352	- 804252	1	466	3606072	1023	603	GT44	GA	1	5	6
332361	- 804287	1	457	3606405	948	488	GT44	GA	1	6	3
332357	- 804374	1	482	3605445	942	464	GT44	GA	1	7	6
332427	- 804357	1	485	3606250	935	394	GT44	GA	1	8	6
332643	- 804415	1	503	3604563	524-	37	GT44	GA	1	9	6
332623	- 804587	1	503	3603560	446-	115	GT44	GA	1	10	6
332561	- 804946	1	503	3604375	618	57	GT44	GA	1	11	3
332515	- 804938	1	457	3606266	729	219	GT44	GA	1	12	3
332462	- 804363	1	484	3606180	868	344	GT44	GA	1	13	3
332554	- 804216	1	518	3607258	962	384	GT44	GA	1	14	3
332587	- 804045	1	506	3608703	1025	460	GT44	GA	1	15	6
332622	- 804016	1	465	3603914	1616	1164	GT44	GA	1	17	6
33195	- 803963	1	421	3606067	1456	987	GT44	GA	1	18	6
331875	- 803893	1	393	3612063	1077	638	GT44	GA	1	19	3
331827	- 803840	1	396	3603438	909	467	GT44	GA	1	20	3
331793	- 803862	1	381	3599289	792	367	GT44	GA	1	21	6
332098	- 804099	1	424	3610530	1629	1157	GT44	GA	1	22	3
332133	- 804139	1	415	3612492	1552	1089	GT45	GA	1	2	3
332173	- 804134	1	452	3611055	1508	1055	GT45	GA	1	3	6
332243	- 804276	1	464	3606828	1179	662	GT45	GA	1	4	6
332281	- 804306	1	463	3606281	1073	556	GT45	GA	1	5	6
331985	- 804166	1	451	3609516	1666	1163	GT45	GA	1	6	6
33193.	- 804156	1	448	3608055	1669	1176	GT45	GA	1	7	6
331866	- 804164	1	436	3607016	1632	1146	GT45	GA	1	8	3
332417	- 803755	1	396	3616422	1674	1239	GT50	GA	1	2	6
332410	- 803782	1	396	3616305	1690	1248	GT50	GA	1	3	6
332402	- 803775	1	396	3615047	1676	1234	GT50	GA	1	4	6
332396	- 803775	1	396	3615945	1670	1228	GT50	GA	1	5	6
332393	- 803773	1	393	3615069	1634	1196	GT50	GA	1	6	6
332385	- 803769	1	405	3615414	1684	1212	GT50	GA	1	7	6
332375	- 803765	1	405	3615227	1680	1207	GT50	GA	1	8	6
332363	- 803760	1	399	3615344	1682	1216	GT50	GA	1	9	6
332359	- 803760	1	402	3615266	1675	1226	GT50	GA	1	10	6
332349	- 803760	1	402	3615133	1677	1228	GT50	GA	1	11	6
332341	- 803791	1	408	3615008	1693	1238	GT50	GA	1	12	6
332319	- 803815	1	427	3613329	1612	1136	GT50	GA	1	13	3
332312	- 803823	1	433	3613086	1616	1133	GT50	GA	1	14	6
332305	- 803830	1	436	3612844	1590	1110	GT50	GA	1	15	6
332301	- 803848	1	436	3612547	1570	1091	GT50	GA	1	16	6
332294	- 803859	1	433	3612398	1572	1090	GT50	GA	1	17	6
332283	- 803869	1	433	3612303	1577	1094	GT50	GA	1	18	6
332279	- 803859	1	433	3612313	1584	1101	GT50	GA	1	19	6
332269	- 803868	1	436	3612047	1591	1095	GT50	GA	1	20	6
332253	- 803865	1	436	3612023	1594	1108	GT50	GA	1	21	6
332252	- 803864	1	439	3611977	1608	1118	GT50	GA	1	22	6
332242	- 803866	1	442	3611875	1620	1127	GT50	GA	1	23	3
332234	- 803876	1	439	3611781	1612	1123	GT50	GA	1	25	6
332229	- 803882	.	433	3611781	1600	1117	GT50	GA	1	26	6
332221	- 803890	.	427	3611734	1598	1112	GT50	GA	1	27	6
332213	- 803897	.	427	3611797	1615	1129	GT50	GA	1	28	3
332205	- 803952	3	427	3611852	1618	1142	GT50	GA	1	29	6
332201	- 803959	3	424	3611914	1625	1152	GT50	GA	1	30	6
332194	- 803914	1	421	3611737	1612	1143	GT50	GA	1	31	6
332194	- 803925	1	418	3611702	1603	1137	GT50	GA	1	32	3

Gravity Data (Concluded)

332163	- 803937	1	416	3611742	1612	1146	GT50	GA	1	33	6
332173	- 803945	1	411	3611991	1617	1150	GT50	GA	1	34	6
332171	- 803952	1	408	3611975	1615	1159	GT50	GA	1	35	6
332167	- 803963	1	398	3612039	1589	1151	GT50	GA	1	36	6
332165	- 803966	1	397	3612219	1595	1164	GT50	GA	1	37	6
332157	- 803977	1	387	3612267	1593	1173	GT50	GA	1	38	6
332149	- 803982	1	378	3612320	1576	1162	GT50	GA	1	39	3
332144	- 803985	1	369	3612405	1567	1175	GT50	GA	1	40	6
332133	- 803994	1	366	3612547	1597	1189	GT50	GA	1	41	3
332131	- 804002	1	366	3612619	1587	1179	GT50	GA	1	42	6
332124	- 804009	1	366	3612652	1596	1188	GT50	GA	1	43	3
332119	- 804016	1	372	3612313	1617	1202	GT50	GA	1	44	6
332169	- 804025	1	387	3612742	1603	1206	GT50	GA	1	45	6
332505	- 804101	1	515	3607703	1066	554	GT50	GA	1	46	3
332546	- 803972	1	500	3608683	1051	473	GT50	GA	1	47	3
332529	- 803975	1	500	3608856	1050	472	GT50	GA	1	48	6
332735	- 803963	1	475	3613644	1189	659	GT53	GA	1	2	3
332733	- 803980	1	462	3613203	1198	661	GT53	GA	1	3	6
332731	- 804009	1	491	3612875	1196	649	GT53	GA	1	4	6
332736	- 804035	1	463	3612966	1189	592	GT53	GA	1	5	6
332740	- 804057	1	488	3612859	1122	578	GT53	GA	1	6	6
332741	- 804066	1	498	3611914	1096	545	GT53	GA	1	7	6
332743	- 804091	1	488	3611668	1043	499	GT53	GA	1	8	6
332746	- 804111	1	491	3611141	1001	454	GT53	GA	1	9	6
332750	- 804136	1	485	3610758	939	398	GT53	GA	1	10	6
332749	- 804161	1	500	3612156	926	369	GT53	GA	1	11	6
332747	- 804191	1	500	3609711	885	327	GT53	GA	1	12	6
332746	- 804216	1	491	3609203	807	260	GT53	GA	1	13	6
332745	- 804242	1	442	3610055	744	251	GT53	GA	1	14	6
332744	- 804263	1	496	3608328	733	182	GT53	GA	1	15	6
332741	- 804289	1	491	3608219	716	169	GT53	GA	1	16	6
332742	- 804306	1	488	3607750	699	105	GT53	GA	1	17	6
332751	- 804339	1	512	3607108	665	94	GT53	GA	1	18	6
332750	- 804369	1	521	3606750	651	70	GT53	GA	1	19	6
332741	- 804413	1	518	3605711	551-	27	GT53	GA	1	20	6
332741	- 804443	1	524	3604719	470-	115	GT53	GA	1	21	6
332751	- 804486	1	533	3603198	332-	263	GT53	GA	1	22	3
332941	- 804091	1	396	3614313	759	317	GT53	GA	1	23	6
332943	- 804116	1	463	3612656	800	283	GT53	GA	1	24	6
332934	- 804136	1	472	3611938	766	239	GT53	GA	1	25	6
332934	- 804156	1	463	3611506	693	180	GT53	GA	1	26	6
332933	- 804179	1	479	3610938	686	152	GT53	GA	1	27	6
332934	- 804200	1	469	3610391	601	77	GT53	GA	1	28	6
332934	- 804225	1	488	3609836	602	58	GT53	GA	1	29	6
332933	- 804243	1	491	3609414	571	23	GT53	GA	1	30	6
332929	- 804269	1	488	3608672	492-	52	GT53	GA	1	31	6
332930	- 804285	1	475	3608701	463-	67	GT53	GA	1	32	3
332931	- 804307	1	475	3608406	426-	104	GT53	GA	1	33	6
332930	- 804330	1	503	3607313	402-	159	GT53	GA	1	34	6
332929	- 804379	1	512	3606672	360-	203	GT53	GA	1	35	6
332929	- 804486	1	539	3604070	205-	396	GT53	GA	1	36	1
332546	- 803975	1	500	3608539	1046	488	GT53	GA	1	39	3
332551	- 803961	1	494	3608675	1053	502	GT53	GA	1	40	6
332553	- 803945	1	497	3609063	1072	518	GT53	GA	1	41	6
332565	- 803929	1	484	3609047	1085	539	GT53	GA	1	42	6
332569	- 803907	1	472	3609069	1072	545	GT53	GA	1	43	6
332581	- 803892	1	463	3610469	1078	561	GT53	GA	1	44	6
332595	- 803879	1	466	3610727	1095	575	GT53	GA	1	45	6
332609	- 803859	1	479	3610992	1138	605	GT53	GA	1	46	6
332621	- 803845	1	475	3611427	1154	608	GT53	GA	1	47	3

Printout of the "GPROF" Program

```
C GRAVITY PROFILING FOR 2-DIMENSIONAL STRUCTURES
C GRAVITY FOR 2-DIMENSIONAL STRUCTURES(AFTER-TALWANI,WORTZEL,LANDISMAN)
C   INPUT(2I10,3F10.3)  CARD NO. ONE
C      LL=NO. OF POLYGONS, NDX=NO. OF GRAVITY VALUES, DX=SEPARATION OF
C      GRAVITY VALUES, XO=POSITION OF FIRST GRAVITY VALUE, SCALE=PLOT
C      SCALE-FOR DRAW
C IF SCALE=0. PROGRAM CALCULATES SCALE
C IF SCALE=13. NO GRAPH IS DRAWN
C   INPUT(FREE FIELD)  LL CARDS
C      NXZ=NO.+1OF CORNERS OF POLYGON TAKEN CLOCKWISE, DRHO=DENSITY
C      CONTRAST, X(I,J),Z(I,J)=CORDINATES OF CORNERS-JTH CORNER OF ITH
C      POLYGON
C   REPEAT SEQUENCE FOR ADDITIONAL PROFILES
C   BLANK CARD AT END TO TERMINATE CALCULATION
      DIMENSION DRHO(50),X(50,20),Z(50,20),NN(50),XX(20),ZZ(20),GAL(500)
   25 READ (5,500) LL,NDX,DX,XO   , SCALE
      WRITE(6,503) LL,NDX,DX,XO
  503 FORMAT(1H1,28HVERTICAL GRAVITY ANOMALY FOR,I5, 9H POLYGONS/2X,
     1 5HTHE,I5,16H-GRAVITY VALUES,,F10.4,19H-KM.APART, BEGIN AT,F10.4)
      IF(LL)  26,26,27
   27 DO 100 I=1,LL
  500 FORMAT (2I10,3F10.5)
      READ(5,501)  NXZ,DRHO(I),(X(I,J),Z(I,J),J=1,NXZ)
      WRITE(6,502)  NXZ,DRHO(I), (X(I,J),Z(I,J),J=1,NXZ)
  501 FORMAT( )
  502 FORMAT(16H NO OF POINTS = ,I10,22H DENSITY DIFFERENCE = /(1X,10F10
     <.3/))
  100 NN(I) = NXZ
      DO 101 I=1,LL
      NNI = NN(I)
      DO 101  J = 1,NNI
  101 X(I,J) = X(I,J) -XO
      DO 102I=1,NDX
      G=0.0
      DO 103 J=1,LL
      NNJ = NN(J)
      DO 104 K = 1,NNJ
      XX(K) =X(J,K)
  104 ZZ(K)=Z(J,K)
      CALL TWLZ(NN(J),XX,ZZ,DRHO(J),GA)
  103 G= G+GA
      GAL(I) = G
      DO 110 M=1,LL
      NNM = NN(M)
      DO 110 N = 1, NNM
  110 X(M,N) = X(M,N)-DX
  102 CONTINUE
      WRITE(6,505) (GAL(I),I=1,NDX)
  505  FORMAT(1X//24H GRAVITY ANOMALY IN MGAL,/(5F15.8))
      ISC=SCALE
      IF(ISC.EQ.13) GO TO 25
      IF(SCALE) 130,131,130
  131 CALL MXSCL(NDX,GAL,SCALE)
  130 CALL DRAW(NDX,1,GAL,SCALE)
      GO TO 25
   26 STOP
      END


      SUBROUTINE DRAW (NTOT, INC, F, SCALE)
C   NTOT=TOTAL NUMBER OF POINTS IN F.  F IS THE DATA (ONE DIMENSIONAL)
C   TO BE PLOTTED, INC IS THE SAMPLE INTERVAL FOR PLOTTING F.
C   SCALE IS THE AMPLITUDE OF ONE FULL SCALE DEFLECTION
      DIMENSION   F(NTOT)
      DATA AA1/1H /,AA2/1H*/,AA3/1H+
      WRITE(6,1011) SCALE,(I,I=9,10)    , (AA2,N=1,2))
 1011 FORMAT(1H1,F14.3,17H-MGALS FULL SCALE/3X,20I5/2X,22A5)
 10   DO 1501 K = 1, NTOT, INC
      FK = 50.*F(K)/SCALE
      KI = FK/50
      KK = FK - KI*50.+50.5
      WRITE (6,511) AA2, (AA1,I=1,KK),AA2
  511 FORMAT (1X,110A1)
 1501 CONTINUE
      RETURN
```

Printout of "GPROF" (Concluded)

```
      SUBROUTINE TWLZ(K1,XX,ZZ,DRHO,GA)
C  USES METHOD OF TALWANI, WORZEL, AND LANDISMAN (JGR 1959 PP 49-59)
C  TO GIVE GRAVITY ANOMALY AT X=0,Z=0. IN MGAL FOR TWO DIMENSIONED
C BODY IN VERTICAL PLANE DESCRIBED BY A POLYGON (IN KILOMETERS
      DIMENSION XX(K1),ZZ(K1)
      PI = 3.14159265
      KK = K1-1
      GA = 0.0
      DO 100 K=1,KK
      K2 = K+1
      IF(XX(K)*ZZ(K2)-XX(K2)*ZZ(K))  30,100,30
   30 IF(XX(K)-XX(K2)) 85,20,85
   20 XZ =        ((XX(K2)**2 + ZZ(K2)**2)/(XX(K)**2 + ZZ(K)**2))
      DG = 0.5*LOG(XZ)*XX(K)
      GO TO 99
   85 IF(ZZ(K)-ZZ(K2))  235,72,235
   72 DG = ZZ(K)*(ATAN2(ZZ(K2),XX(K2))-ATAN2(ZZ(K),XX(K)))
      GO TO 99
  235 A =(XX(K2)-XX(K))/(ZZ(K2)-ZZ(K))
      B = (XX(K)*ZZ(K2) - XX(K2)*ZZ(K))/(ZZ(K2)-ZZ(K))
      IF(XX(K))  200,201,200
  201 DG = (B/(1.+A*A))*(.5*LOG((XX(K2)*XX(K2)+ZZ(K2)*ZZ(K2))/(ZZ(K)*
     1  ZZ(K))) - A*(ATAN2(ZZ(K2),XX(K2))-PI/2.))
  200 IF(XX(K2))  31,210,31
  210 DG = (B/(1.+A*A))*(.5*LOG(ZZ(K2)*ZZ(K2)/(XX(K)*XX(K)+
     1  ZZ(K)*ZZ(K))) + A*(ATAN2(ZZ(K),XX(K)) - PI/2.))
   31 DG=LOG((XX(K2)*XX(K2)+ZZ(K2)*ZZ(K2))/(XX(K)*XX(K)+ZZ(K)*ZZ(K)))
      DG=(B/(1.0+A*A))*(0.5*DG-A*(ATAN2(ZZ(K2),XX(K2))-ATAN2(ZZ(K),
     1XX(K))))
   99 GA=(13.34)    *DRHO*DG + GA
  100 CONTINUE
      RETURN
      END


      SUBROUTINE MXSCL(N,A,AMAX)
      DIMENSION A(N)
      AMAX = 0
      DO 26 I = 1,N
      IF (ABS(A(I))-AMAX) 26,26,25
   25 AMAX = ABS(A(I))
   26 CONTINUE
      RETURN
      END
```

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